INTEGRATING THE PLANNING OF GREEN SPACES AND SUSTAINABLE DRAINAGE SYSTEMS

BY

Rohit Singh BSc, MSc

A thesis submitted in partial fulfilment of the requirements of The University of Abertay Dundee for the degree of Doctor of Philosophy

March 2012

I certify that this is the true and accurate version of the thesis approved by the examiners

Signed.[redacted] **Date..**9th March 2012

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ACKNOWLEDGEMENTS

This research would not have been possible without the guidance and the help of several individuals and organizations who in one way or the other have contributed their valuable assistance to the preparation and completion of this study.
First and foremost my gratitude goes to Prof. Chris Jefferies, University of Abertay Dundee who supervised my work with great sincerity and encouragement. He has been a source of inspiration for me and also provided psychological support during many times of my research. I would also like to thank my second supervisor Dr. Rebecca Wade who found time to review my work and provided me with much information about current research initiatives. I am also grateful to the team at UWTC comprising researchers and academics that have provided me with motivation. Thanks also to Dr. Virginia Stovin who provided critical inputs into my research during the starting phase of my research.

This research would also not have been possible without the funding support from Glasgow City Council. In particular I would like to thank Sandy Gillon and George Morrison who took keen interest in my work and helped to provide the key resources and data from Glasgow City Council (GCC). I am also grateful to other planners from GCC and Renfrewshire City Council who also provided valuable inputs into my work.

Last but not the least, I would like to thank all my family members who have always stood by my side and encouraged me to finish this research.

Abstract

In recent times urban flooding has become more frequent and more complex due to the effects of increasing urban areas and climate change. In some established urban areas the existing drainage infrastructure is unable to cope with the volume of surface runoff and flooding events are more frequent, therefore new approaches to create more space for water within developments are required. This research was conceived in that context. It aims to investigate the potential for integrating green space planning with water planning and to develop a framework for the same in order to reduce the risk of flooding.

An extensive literature review was carried out in the areas of urban planning, water planning, planning legislations, and issues related to integrating green space and water planning. The review identified the need for an inclusive framework which could integrate aspects of green space and storm water planning more holistically to achieve greater spatial planning efficiency. To satisfy this need, a conceptual framework was developed which took into consideration the opinions of various stakeholders. The conceptual framework included green spaced planning for SUDS, recreational and storm water indicators and a mechanism for integrated evaluation of SUDS for recreation and storm water management.

The conceptual framework provided a joint approach where both engineers and planners will need to work together for the development of integrated storm water and green space plans. The framework showed processes for both disciplines and also indicates how spatial planning and water planning interfaced so that there was clarity of roles. In order to evaluate integrated plans, an 'integrated evaluation tool' was developed which uses indicators from both the areas of green space planning and water planning. The evaluation tool also contained a scoring system which can be used to select storm water management options with more recreational potential. The tool provides a mechanism to balance the requirements of recreation and storm water management so that more holistic solutions can be developed by teams of engineers and planners.

The conceptual framework and the integrated evaluation tool were applied to two case study catchments. Results from the case studies showed the relationship of spatial planning and flooding. It further tested whether recreational aspects could be integrated into storm water planning. A number of drainage options were tested to show the application of the evaluation tool under various scenarios.

This results of the research showed that the conceptual framework was appropriate in both case study areas even though the areas had different patterns of development. It is therefore proposed that the approach has potential for wider application in other geographical areas. Results from the two areas also showed that the integrated approach established in this research could enhance the recreational aspects associated with urban storm water management.

The framework presented in this thesis will potentially be of use to a wide range of stakeholders such policy makers, local authorities, water companies, consultants and researchers. It could also be useful in informing the evolution of planning policies and technical guidance associated with water and green space planning.

Keywords: storm water management, SUDS, urban planning, green space planning, amenity indicators, and storm water quantitative indicators.

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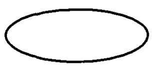
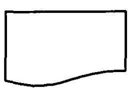
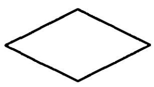
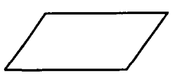
List of abbreviations and acronyms

GCC	Glasgow City Council
LPA	Local Planning Authority
RSS	Regional Spatial Strategy
PPS	Planning Policy Statement
OPSI	Office of Public Sector Information
SEPA	Scottish Environmental Protection Agency
SPP	Scottish Planning Policy
SUDS	Sustainable Urban Drainage Systems
SWMP	Storm Water Management Plan
PAN	Planning Advice Note
TCPA	Town and Country Planning Association
UNEP	United Nations Environmental Programme
WFD	Water Framework Directive

Key to symbols used in framework flow-charts

	Process
	Inputs from professionals of a discipline for example: planners, engineers
	Next step
	Document used For example: PPS 25
	Decision
	Change of Stage (used for conceptual framework)
	Input of data

1. INTRODUCTION

1.1 INTRODUCTION

Sustainable Urban Drainage Systems (SUDS) are attracting increased attention due to their ability to attenuate flow, reduce flooding and improve water quality. However, planning of sustainable storm water management remains unclear in the context of urban spatial planning. Also, urban areas within the UK are undergoing expansion and regeneration to improve quality of life for urban dwellers, which is being constrained by limited capacities in existing sewer systems. Hence, there is a need to investigate the opportunities for SUDS within the existing urban landscape.

Planning of urban developments is often not harmonised with the natural landscape, particularly water environment planning. There is frequently a perception that development planning cannot coexist with the natural environment. In order to reduce flooding, green spaces could offer abundant areas for storm water management. The amenity and recreational aspects associated with SUDS have been well researched by Apostolaki (2007), Emmerling-DiNovo (2007) and other researchers. These authors highlight several benefits, such as enhancement of wildlife, amenity value and reduction of flooding, among others. Therefore, there is a case for integrated planning of SUDS and green spaces. Such an holistic planning approach would not only allow developments to occur without causing the detrimental effects of flooding or poor water quality in watercourses; it would also promote the multifunctional use of green spaces, such as recreational and pedestrian uses for flood attenuation sites. Some of the new developments, such as DEX in Dunfermline in the UK, are taking steps in the right direction, as they promote greater integration of water in the landscapes of new developments.

The need for new integrated approaches of spatial planning is increasingly being felt due to climate change. In the past, there has been little evidence of attempts by professional planners to make the adaptations necessary to face scenarios of climate change (Wilson 2006). The need for new planning approaches became more acute after the devastating 2007 flooding in the UK. The Pitt Review, commissioned in the wake of 2007 flooding, also identified the need for adopting SUDS in England and Wales (Pitt 2008).

The research presented in this thesis was sponsored by Glasgow City Council to resolve flooding problems in innovative ways. However, the scope of the research was enhanced to develop a more generic methodology by including aspects of green space planning and water planning. There was very keen interest among the local authority officials in developing a methodology for integrated green space and water planning. Apart from resolving flooding incidents, enabling future development was another driver for the local authority commissioning this study, as traditional solutions were not working at the catchment scale.

The results of the project will be of interest to local authorities, Scottish Water, SEPA, and researchers looking for holistic multidisciplinary approaches to water management. Multi-functional planning of SUDS is increasingly being adopted by authorities, both in the UK and internationally. Planning of green spaces is also undergoing a change, with the quality, as well as the quantity, of green spaces becoming increasingly relevant (Dunnett, Swanwick, and Woolley 2002; Greenspace Scotland 2010). This research aims to combine the emerging aspirations of providing high quality green spaces and high amenity SUDS.

The central aim of this research is to investigate the potential for integrating green space planning with storm water planning. This research was timed appropriately, as there has been an increasing interest in sustainable development and global environmental changes in recent years (Haughton and Hunter 2003). Urban water management is shaped by several criteria, such as land use, natural resources planning, people's perception of the existing and desirable states of urban environments, availability of resources and local policy goals (Wagner, Marsalek, and Breil 2009). It was pertinent, therefore, to investigate the link between water planning and green space planning. Hence, the following questions were selected for research:

- *What distributions of green space are most favourable for planning SUDS?*
- *What are the integrated indicators for storm water and green space planning?*
- *How should integrated water and green space planning be evaluated?*

The overall research outline is presented in Figure 1-1.

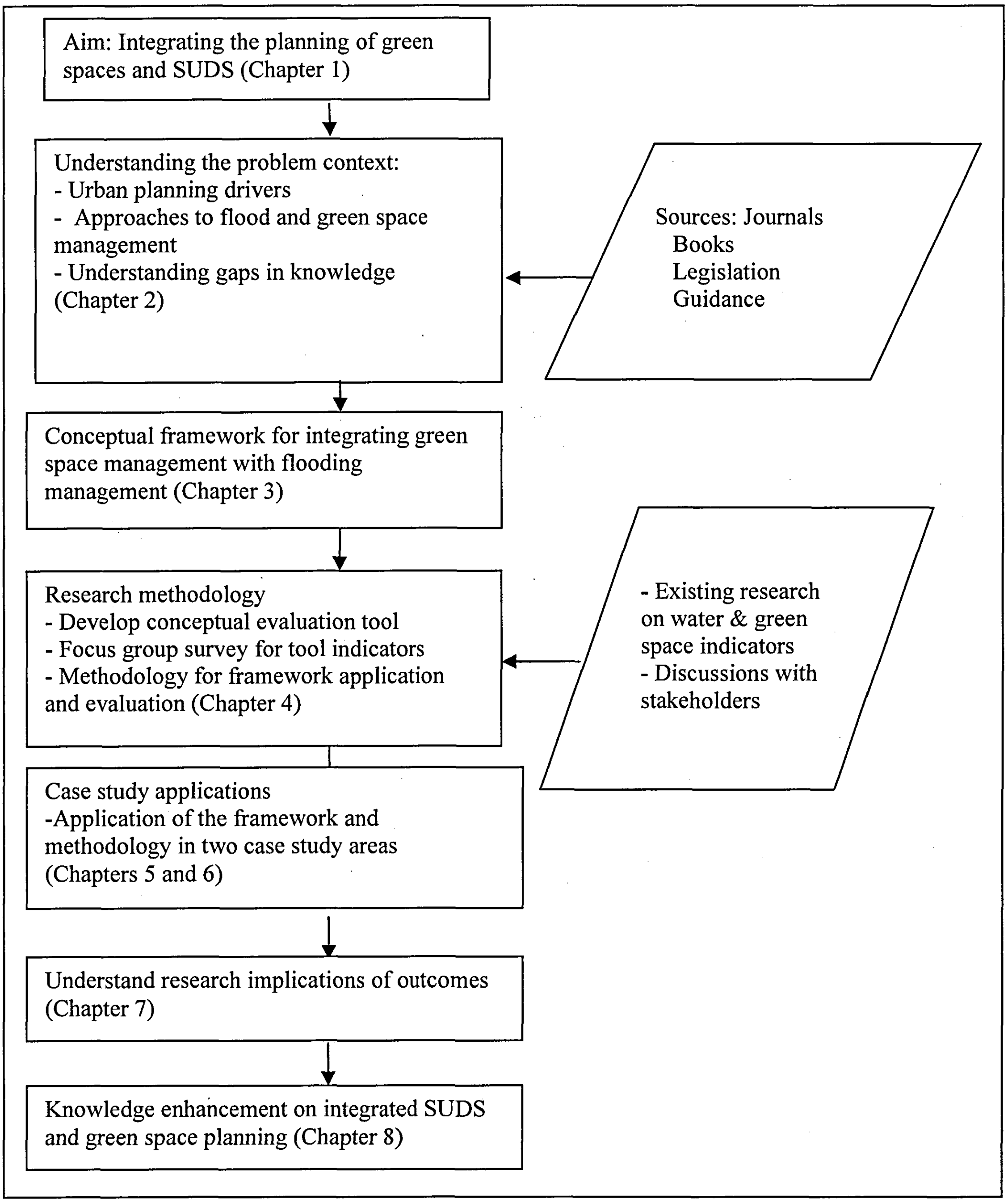


Figure 1- 1: Thesis overview

1.2 AIMS AND OBJECTIVES

This thesis has two aims as presented below:

- Investigate the potential for integrating green space and water planning as a means to reducing the risk of flooding in urban areas with impermeable soil.
- Develop a framework for integrating green space planning with water planning.

The following objectives were adopted to achieve the aims:

- To undertake preliminary analysis (using existing literature sources and new case study data) to understand and establish, in broad terms, an approach that might be used in integrating storm water planning and spatial planning.
- To develop a detailed framework for application of integrated green space planning at a catchment scale, as well as to evaluate the benefits for improvement of storm water management.
- To identify indicators associated with amenity and quantitative storm water management.
- To develop an integrated scoring tool involving the integrated indicators.
- To apply the proposed methodology in a case study catchment to demonstrate its use for spatial planning.
- To apply the methodology in another catchment to provide evidence that it is more generally applicable in similar situations.
- To evaluate the proposed integrated green space and water planning methodology in the context of the existing spatial planning framework, and understand its implications for legislative and institutional planning issues.

1.3 STRUCTURE OF THESIS

The following sections discuss how the structure of this thesis reflects the key aims and objectives of this study.

Chapter 2 – Literature Review

The second chapter presents a review of the key literature considered relevant to this research project. This review explores:

- The background to the spatial planning and its legislative context
- The drivers for land use planning
- legislation and guidance related to planning and flooding
- Shifting paradigms of urban drainage systems
- Issues associated with green space planning
- Previous research into integration of water planning with green space planning.

The review of existing spatial and drainage planning approaches, as well as research into new approaches, provided information about the overall context of the research. It also helped in understanding the gaps in knowledge of integrated water and green space planning and the need for further research.

Chapter 3 – Proposed framework for integrated water and green space planning
Chapter 3 describes the conceptual framework generated as a hypothesis after understanding the gaps in existing knowledge. This framework comprises six stages, involving aspects of both water and spatial planning. As it is a multi-disciplinary approach, this framework also identifies the roles of various disciplines involved in the different stages of the framework. A methodology to implement this conceptual framework is developed in Chapter 4.

Chapter 4 – Research Methodology
In order to apply the proposed framework developed in Chapter 3, case study was identified as the research methodology and a tool was developed for evaluation of various SUDS options. This tool included both amenity and storm water management indicators. Previous research into green spaces and SUDS provided the knowledge for extracting indicators, which were then discussed with a focus group of academicians and practitioners associated with disciplines of both water and urban planning. The various hypotheses developed were applied in the case study catchments described in Chapters 5 and 6 respectively.

Chapter 5 - Application of proposed framework to Light Burn catchment
Chapter 5 presents application of the conceptual framework developed in Chapter 3 to Light Burn catchment, in the East End of Glasgow. Investigations for analysis of flooding and spatial planning were carried out at both the catchment and sub-catchment scales. A number of SUDS options were proposed with different storm water and amenity aspects. Hydraulic models, obtained from drainage consultants, were used for the hydraulic assessments in these options. The integrated evaluation tool, proposed in Chapter 4, was used to evaluate the proposed SUDS options and preferred options were selected.

Chapter 6 – Application of proposed framework to Spateston Burn catchment

Chapter 6 presents the application of the methodology in a second case study catchment in order to test its applicability in a totally different area, i.e. within Renfrewshire. The basic approach of the investigation was similar to that in Glasgow. However, this case area had a different pattern of development and constraints, which led to greater understanding of factors promoting integrated water and green space planning. Application of the methodology in this area provided greater confidence in the indicators, which were applied in this catchment.

Chapter 7 – Evaluation/Discussion of work

This chapter presents a comparison of the two case studies. The interpretations of the results of the two case studies in the context of existing knowledge were also discussed. The implications for legislation and planning guidance are explored to understand the scope for improvement of existing frameworks. Benefits in the areas of flood management and green space planning are identified. The methodology can be used by planners and engineers to understand the requirements of integrated planning. Research implications for SUDS and green spaces are also discussed. Finally, limitations of the work are enumerated in the context of existing literature.

Chapter 8 – Conclusions and recommendations for further work

Chapter 8 summarises the research that was undertaken in this thesis, a number of conclusions were drawn and highlighted the potential for further work. The studies show that the proposed methodology was applied to two different urban catchments, which indicates its potential for application in other areas. Recommendations, based on the results of this research, were also provided to aid policy development, institutional decision-making, and planning of green spaces and storm water in urban areas. The work has created an area where a considerable amount of future work could be undertaken to further improve the understanding of water sensitive urban planning.

2 LITERATURE REVIEW

2.1 INTRODUCTION

This chapter develops the context for research in the field of 'flooding and spatial planning' by examining existing literature. Section 2.2 describes Urban Planning and its components, such as housing, industrial, retail, transport and green space planning. Legislation and regulations related to planning and flooding are reviewed in Section 2.3. Section 2.4 describes the various guidance documents available for planning and designing drainage systems in Scotland and England. The shifting paradigm of urban drainage systems is presented in section 2.5, which explores the journey from conventional drainage systems to more sustainable approaches. Section 2.6 deals with the context of integrating water planning into green space planning. Based on the review of literature, the gaps in integrated planning of green spaces and SUDS planning are reviewed in section 2.7.

2.2 URBAN PLANNING

This section describes key aspects of urban planning and the system as practised in the UK; especially in Scotland and England.

Urban planning is based on spatial and non-spatial aspects of planning. Non-spatial aspects are related to social and mathematical sciences, while spatial planning is based on a prescriptive normative theory that has roots in Utopian thoughts. Planning of services such as legal system, health system, education are examples of non-spatial planning while zoning of areas into industrial, residential, institution and recreational area is the spatial aspect of planning (McConnell 1981).

Chapin (1965) defines town planning in the spatial context as:

"*While taking into account its inter-relatedness with transportation and utility planning, land use planning is basically concerned with the location, intensity and amount of land development required for various space-using functions of city life - industry, wholesaling, business, housing, recreation, education, and the religious and cultural activities of the people. Fundamentally a land use plan is part of an overall* *plan which embodies a proposal as to how land should be used as expansion and renewal proceed into the future*".

The Town and Country Planning Act (1947) created the framework for the town and country planning system in the United Kingdom. It introduced the system of planning permission, wherein local planning authorities were responsible for deciding whether a development should go ahead or not (Cullingworth and Nadin 2002).

The Town and Country planning Act (1990) further consolidated the system as it exists today. It created institutional and spatial development mechanisms which improved the framework for the Local Planning Authority. Planning documents (structure and local plans) and controls over development were introduced (OPSI 1990). Further, provisions were introduced for local infrastructure planning through the Planning Act 2008, as described later in this section. The main planning legislation for Northern Ireland is The Planning (Northern Ireland) Order 1991 (OPSI 1991). Planning in Scotland is governed by the Town and Country Planning (Scotland) Act 1997 (National Archives 1997) and the Planning etc. (Scotland) Act 2006 (OPSI 2006). The planning systems of Scotland, England and Wales are essentially the same, but differ because of common law differences.

The Planning Act (2008) introduced a new streamlined system for decisions on applications to build nationally significant infrastructures in England and Wales, alongside further reforms to the town and country planning system through the introduction of a Community Infrastructure Levy (CIL). The levy could be useful in the development of community infrastructure, such as flood management, water and waste water management, and green infrastructure (Communities and Local Government 2009a).

Policy instruments have been further developed by the four countries comprising the UK, i.e. England, Scotland, Wales and Northern Ireland. In England and Scotland, these are called Planning Policy Statements (PPS) and Scottish Planning Policy (SPP) respectively. The Scottish Planning Policy is a consolidated regulation formed by amalgamation of several planning policies in Scotland (Scottish Government 2010). In Wales and Northern Ireland the planning policy instruments are known as Planning

Policy Wales (PPW) and Planning Policy Statements (PPS) (Cullingworth and Nadin 2002).

Development Control

Development control is a wide ranging subject and embraces several aspects related to the use of land. It is concerned with the real substance of development, such as legal procedures for the planning of buildings, roads and other infrastructure operating at various scales, ranging from human to regional and national scales. A number of professions, like architects, engineers, surveyors, landscape architects, lawyers, financial experts, politicians and administrators, are involved to ensure that a plan fits into the environment. The type of activity in the adapted spaces is another important aspect of development control. For example, the type of roads, open spaces and parking requirements would vary, depending on whether an area is residential or commercial (Thomas 1997).

Consent - known as planning permission – is required for new buildings or before making major changes to existing buildings or to the local environment. Each application for planning permission is made to the local planning authority for the area. The application must include enough detail for the authority to see what effect the development could have on the area (Communities and Local Government 2009b).

Local Spatial Planning

Local Spatial Planning sets out the key ingredients of local spatial plans and the key government policies on how they should be prepared. Local challenges and opportunities should be taken into account by local planning authorities in preparing development plan documents and other local development documents. In England, these policies are contained in Planning Policy Statement 12 (PPS12) (Communities and Local Government 2008).

The term 'local planning authority' usually means the district or borough council - not the parish or town council. The planning system is needed to control development in an area. Each local authority must produce a Local Development Framework, which outlines how planning is managed in the area. It is important that individuals and communities are involved when the documents are prepared (Communities and Local Government 2008).

There are two components of the local plan: the structure plan and the local plan. Structure plans are meant to provide a strategic planning framework for at least 15 years ahead, resolving the balance between development and conservation. Local plans contain detailed policies and specific proposals for development and use of land. The allocation of land for various uses, such as housing or industrial, is based on these policies (Adams 1994).

Local plans also take into account the flood risks associated with various sites. They show areas at risk of flooding and allocate sites for particular land use and development proposals (Communities and Local Government 2008). The policies for flooding are contained in Planning Policy Statement 25 and discussed in section 2.3.

Regional Spatial Planning

The objective of the Regional Spatial Strategy (RSS) in England and Wales and the National Planning Framework in Scotland is to contribute to the achievement of sustainable development (Scottish Government 2004a). The RSS, which normally incorporates a Regional Transport Strategy (RTS), provides a broad development strategy for the region over a fifteen- to twenty-year period. The RSS also informs the preparation of Local Development Documents (LDDs), Local Transport Plans (LTPs) and regional and sub-regional strategies and programmes; all of which have a bearing on land use activities.

Following the commencement of the Planning and Compulsory Purchase Act 2004, Regional Planning Guidance (RPG) became RSS in each region of Wales and England outside London, and now forms part of the statutory Development Plan - PPS 11 (Communities and Local Government 2009c).

Land use and land cover are important determinants of the state of the natural environment. Consequently, measures of land use and land cover change have been widely used as indicators of environmental condition and quality (Potschin 2009).

The following sections discuss the urban planning considerations relevant to different land use planning types.

Housing

Housing demand is a major issue in urban areas and it is important to provide proper affordable housing for all. The roots of housing change lie in two broad areas. Demographic and social changes directly influence the number of homes required. Secondly, economic changes determine the quantity and type of housing that is built, the nature of demand and how much people are able to pay for housing (Marsh and Mullins 1998).

The housing policy, as set out in the Scottish Planning Policy, encourages efficient supply of new housing land, together with the required infrastructure of transportation, educational institutions, green spaces and employment opportunities. It also encourages development of existing brown field sites (Scottish Government 2010). English housing policy, in PPS 3, has a similar approach (Communities and Local Government 2011).

The purpose of housing is to meet the human need for shelter and it is intuitively understood that housing construction may potentially damage or destroy the local ecosystem. However, the designing of housing could become more integrated by including principles of ecological engineering (Pei *et al.* 2009). Redman (1999) has also suggested that the need for building intellectual bridges between life, earth, engineering and social sciences is a necessity for creating better ecosystems. A well thought out development can create great opportunities for good housing and a natural environment with integrated features for flood management, as witnessed in the Ardler housing development (Scottish Government 2010). Figure 2-1 shows the housing area surrounding the pond in Ardler village in Dundee, Scotland as an example of integrated housing planning (British Homes Awards 2007).

Figure 2-1: Pond and adjacent new housing in Ardler village Dundee, Scotland
(Source: British Homes Awards 2007)

Business/Industry

Land use planning, related to business and industry, sets out clear economic vision and strategy, and proactively encourages sustainable economic growth through identification of priority areas for investment, as stated in PPS 4 (Communities and Local Government 2009d).

Business and industry are of two types: manufacturing and service. Manufacturing includes factories producing goods on a large scale, while services include generating and selling services, such as medical, hotel, food, offices, etc. The factors affecting industrial/ business locations are: Labour quality and quantity, transport and communications, site and premises, government aid and environment factors (Glasson 1978). Although industries provide employment, they have from start been plagued with the problem of pollution (Sell 1992). Generally, environmental pollution of air, water and land is linked to industrial activities (Glasson, Therivel, and Chadwi 2005). Environmental regulations and pollution abatement by firms determine the pollution in various sectors of industry (Cole *et al.* 2005). In the UK there are various legislations limiting the release of effluents into water, as discussed later in section 2.3.

Retail

The basic classification of shopping centres is derived from the size of the area from which they draw their trade. According to the size of the catchment area, three main classes of centres can be recognised:

- the local neighbourhood centre for convenience goods (within walking distance) (serving 10,000 people)
- the district or community centre (40,000 people)
- the regional or main centre (100,000 people)

(Gosling and Maitland 1976)

Pharoah (1996) recommends that the planning of retail sites could be done in such a way that it promotes walking and public transportation, while Leslie *et al.* (2007) suggest that a higher density of neighbourhood retail is necessary for promoting walkable access to retail centres.

Transport

The problems associated with moving about in an urban area led to the development of transportation planning. The aim of transportation planning, until recently, has been mainly to serve the functional needs of traffic. However, more recently, transportation planning has undergone a paradigm shift, with its focus shifting towards influencing the accessibility of locations and reducing the need to travel within the urban area (Pharoah 1996; Communities and Local Government 2006). Ravetz (2000) describes the conventional approach as transportation engineering, where the focus is on mobility, while the real issue is that of accessibility, which he describes as an urban form or an activity pattern that enables access to homes, jobs and services with the greatest social equity, the least travel and lowest impact modes. Transportation, although an important service, also causes a major problem in terms of pollution to the environment (Barton 2009).

Arnold and Gibbons (1996) have described impervious areas as key environmental indicators for storm water. This is due to the fact that roads and car parks constitute a traffic carrying component of urban paved areas, which causes pollution to water bodies. Pollution, as well as runoff from roads, could be reduced by adopting SUDS, described in section 2.4.

Green space

Green spaces are central to providing natural recreation in urban areas. Green spaces (e.g. parks, farmland, playgrounds, natural areas, etc) are dominated by a "natural" environment, composed of abiotic (soil, water, minerals) and biotic (plants, animals, micro-organisms) elements, while a built environment represents a high level of intervention in the ecosystem, altering the landscape and interfering with natural processes, sometimes irreversibly (Maruani and Amit-Cohen 2007). Green spaces are defined as land that consists predominantly of unsealed, permeable, soft surfaces, such as soil, shrubs, grass and trees; the typology of green spaces is presented in Dunnett, Swanwick, and Woolley (2002). Different types of green spaces provide recreational opportunities, as described in Table 2-1.

There has been increasing recognition of the value of green spaces and the wide range of ecosystem services they provide (as detailed in section 2.6.2). These services are provided by street trees, lawns/parks, urban forests, cultivated land, wetlands, lakes/sea and streams (Bolund and Hunhammer 1999). Investigations by Tratalos *et al.* (2007) indicate that ecosystem quality tends to decline as urban density increases, although for a given urban density, appropriate proportion and configuration of green spaces can maximise ecological performance.

According to Planning Policy Guidance note (PPG 17) in England and SPP in Scotland, the local authorities are responsible for delivery of quality and accessible green spaces. In addition to local authorities, Greenspace Scotland and Natural England also play an important role in policy advocacy, partnership development, support, research and sharing practices.

Table 2-1: Typology of urban green spaces (Dunnett, Swanwick, and Woolley 2002)

All Urban green space	Amenity Green Space	Recreation green space	Parks and Gardens Informal Recreational Areas Outdoor sports areas Play areas
		Incidental green space	Housing green space Other incidental green space
		Private green space	Domestic gardens
	Functional Green Space	Productive green space	Remnant farmland City farms Allotments
		Burial grounds	Cemeteries Churchyards
		Institutional grounds	School grounds Other institutional grounds
	Semi-natural Habitats	Wetland	Open running water Marsh, Fen
		Woodland	Deciduous woodland Coniferous woodland Mixed woodland
		Other Habitats	Moor/ Heath Grassland Disturbed ground
	Linear Green Space	Linear green space	River and canal banks Transport corridors (road, rail, cycleway and walking routes) Other linear features (e.g. cliffs)

In Scotland, 'Greenspace Scotland' supports a Scotland-wide network of green space partnerships involved in creating, improving and managing urban green spaces. This organisation has supported several research projects aimed at demonstrating the links between communities and green spaces (Greenspace Scotland 2010). A similar vision for integrated green spaces has been enunciated by Natural England, which has launched initiatives to demonstrate how both large and small developments can incorporate green infrastructure in practice (Natural England 2010a).

Water and flood planning

Planning for water in urban areas has been one of the difficult areas in planning due to the transient nature of water. In recent years, flooding has been increasingly intense, obstructing critical infrastructure such as rail services, as shown in Figure 2-2. The BBC (2009) reported that thousands of people were forced to leave their homes amid severe flooding across England and Wales in 2007 and it was believed to have claimed four lives.

Figure 2-2: Flooding of rail tracks (BBC 2009)

Flood damage potential has changed tremendously since the 1990s leading to shifting of policy from flood defence to living with water. This has resulted in the development of a new strategy by DEFRA titled 'Making Space for Water' (Johnson, Penning-Rowsell, and Tapsell 2007). This strategy raised key issues regarding the need to change the approach towards drainage planning. It recommends the need for a more holistic approach involving catchment-based planning in view of the greater risk posed by climate change. The policy paper also advocates the need for better awareness to reduce the risk of damage from flooding. Further, better land use planning and integrated drainage management is recommended in order to reduce the risk of flooding (DEFRA 2005). Research funded by DEFRA's 'making space for water strategy' concluded that flood risk mapping was feasible for sewer and over land flooding. This was carried out using new methods of modelling, which involved integrating 1D and 2D modelling (Hankin *et al.* 2008).

After the devastating flooding in 2007 management of urban flooding got more attention and the Pitt Review was commissioned. The Pitt Review suggests that there must be a step change in the quality of flood warnings. This can be achieved through closer cooperation between the Environment Agency, the Met Office, and improved modelling of all forms of flooding. The public and emergency responders must be able to rely on this information with greater certainty. The review recommended a wider brief for the Environment Agency and asks councils to strengthen their technical capability in order to take the lead on local flood risk management. It envisages further protection for communities through robust building and planning controls (Pitt 2008). However, the review does not suggest solutions to the existing problems of flooding with the use of SUDS techniques. Its main orientation was towards reducing the economic damage from flooding.

Management of storm water has been handled by different agencies depending on their source which resulted in difficulties in integrated approach towards management (McMaster and Baber 2011). However, Flood and Water Management (2010) reduced the conflicts and proposed overarching framework. Pitt review also resulted in SWMP guidance from DEFRA (2010a) which suggested the need for local surface water management plans co-ordinated by local authorities. It outlines four phases: preparation, risk assessment, options appraisal, and implementation of an action plan. These four phases provide a framework for undertaking a SWMP study. It may also be used to co-ordinate and strategically plan the drainage in all new developments which could be useful for efficient planning of SUDS.

2.3 PLANNING AND FLOODING: LEGISLATION AND REGULATIONS

Important legislation and regulations associated with planning and flooding are analysed in this section.

Planning in England

1) Planning Policy Statement (PPS) 25

PPS 25 introduced a risk-based framework for planning of flood management. The policy envisaged a source-pathway and receptor model for development planning in flood prone areas. It advocated a strategic approach through policies in Regional Spatial Strategies (RSSs) and Local Development Documents (LDDs). Further, it required management of flood pathways through appropriate design of developments and maximisation of SUDS opportunities. The adverse consequences of flooding on the receptors (people, property, infrastructure, habitat and statutory sites) should be mitigated by avoiding inappropriate development in areas at risk of flooding. PPS 25 assigns responsibilities to various planning stakeholders: The developers, the Regional Planning Body, the Local Planning Authority, the Environment Agency, and other bodies. The owners and developers have primary responsibility for avoiding flooding; safeguarding their properties against flooding by demonstrating that they are compliant with the policies in PPS 25. The Regional Planning Body is required to develop a Regional Flood Risk Assessment (RFRA) for planning housing and infrastructure at a regional level. Implementation of the framework at a local level is done through a Strategic Flood Risk Assessment (SFRA) by local planning authorities. Implementation of PPS 25 has not been effective, resulting in flooding at various places (White and Richards 2007). There have been major institutional and communication failures in the implementation of the framework. These deficiencies were identified in Pitt (2008) after the major flooding in 2007. The findings of the Pitt Review and its recommendations were presented in the previous section.

2) Water Environment (Water Framework Directive) (England and Wales) Regulations 2003

The Water Framework Directive (WFD) was implemented in England and Wales through the Water Environment Regulations 2003. It provided development of a strategic planning process for river basin planning districts for sustainable water environment improvement. A monitoring mechanism was created through the regulations to evaluate the chemical and ecological potential of water (OPSI 2003).

3) Flood and Water Management Act 2010

The Flood and Water Management Act (2010) was designed to fulfil the recommendations of the Pitt review. It proposes enhancement of the remit of the Environment Agency and requires local authorities to take a lead role in local flood risk management. Hence, it reduces the earlier storm water problems related to management by multiple agencies. The Act, for the first time, endorses the idea of SUDS adoption by local authorities and could, therefore, introduce a regime for sustainable urban drainage systems in England. However, the Act does not recommend retrofitting SUDS to replace the existing storm water management infrastructure (OPSI 2010).

The legislation has resulted in a co-ordinated approach by various stakeholders, such as the local authority, water companies and the Environmental Agency/ Scottish Environment Protection Agency (SEPA). Already, several Surface Water Management Plans (SWMPs) are being prepared by local authorities in various parts of the UK the progress made on SWMPs varies from one local authority to another, depending on the availability of resources (DEFRA 2010b).

Planning in Scotland

1) SPP: Scottish planning policy

The policies associated with flood management and control for Scotland is contained in the SPP. According to the policy surface water from all new developments except single houses require SUDS to reduce the impact both hydraulically and pollutant removal before it discharges into watercourses. SPP also contains a risk framework to provide for a basis for decision making related to flood risk. According to the framework risk is depending on the probability of flooding (Scottish Government 2010).

2) PAN 69: Planning and Building Standards Advice on Flooding

This Planning Advice Note (PAN) guidance describes the responsibilities of local authorities and developers in ensuring future built developments are not located in areas with a significant risk of flooding. The first part of the document enumerates background information on the water environment and the factors which lead to flooding. The document also contains advice on addressing flood risk in development plans. This PAN promotes the use of sustainable measures such as SUDS and also indicates the potential for retrofitting SUDS in existing developments (Scottish Government 2004b).

3) PAN 61: Planning and Sustainable Urban Drainage Systems

This PAN deals with SUDS and provides practice advice to the planners and the development industry. The guidance recognises that the planning of SUDS require a number of agencies and disciplines (planners, developers, engineers, architects, landscape architects, ecologists and hydrologists) to work in a partnership. Planners have a central co-ordinating role in getting SUDS accepted as an integral part of the development process. The planners have a role of guiding the process from preapplication discussions through to decisions in bringing together different parties guiding them to solutions which can lead to sustainable development (Scottish Government 2001).

4) PAN 79: Water and drainage

This document provides advice in relation to provision of water and drainage in the planning context. The policy encourages joint working effective and participation by all stakeholders to enable appropriate development to proceed. It also clarifies the role of planning authority to inform the planning and delivery of new infrastructure. PAN 79 also specifies the role of Scottish Water and SEPA indicating how they interact with the planning system (Scottish Government 2006).

5) Water Environment and Water Services (WEWS) Act 2003

The Water Framework Directive was transposed into Scottish law in 2003 by the Water Environment and Water Services (Scotland) Act 2003. The act set in motion the River Basin Management Planning (RBMP) process to achieve improvements in the water environment in a sustainable way. It also required production of annual reports detailing progress on the implementation of the Water Framework Directive (Scottish Government 2003).

6) Flood Risk Management (Scotland) Act 2009

This act was passed in Scottish parliament on 13th May 2009 to make provision for sustainable flood management. It makes specific provisions for the functions of local authorities and SEPA in relation to flood risk management, and amends the Reservoir Act 1975. The act requires SEPA to create flood hazard maps, flood risk management plans, and mapping of natural water bodies and artificial structures. It also provides for local flood risk management plans by local authorities, and sewer flood management by Scottish Water (OPSI 2009).

2.4 DEVELOPMENT OF SUDS AND WATER QUALITY

Water quality has been an important driver for planning of SUDS in Scotland. The concept of Best Management practices termed Sustainable urban drainage systems (SUDS) was introduced in Scotland by SUDS working Party to control diffused pollution (Darcy 2001). The emphasis on treatment train which includes source control, site control and regional control has been recommended by the CIRIA SUDS guidance (CIRIA 2000) to provide three levels of treatment to storm water.

Sewers for Scotland (WRc 2007), is a guide developed by WRc (Water Research Centre) for use by developers in Scotland for the provision of sewerage. It details the procedures and provides guidance for the design and construction of such infrastructure. The document is consistent with the Sewerage (Scotland) Act 1968 with respect to the provision of sewerage infrastructure for housing and industrial/commercial developments. The 2nd edition of the document covers SUDS in addition to conventional systems. It recommends a design principle that the runoff from the developed site should mimic the quality and the quantity of the runoff from the site in its greenfield state as far as practicable. It is similar to Sewers for Adoption in relation to the design of infrastructure, but contains additional information, relevant to the Scottish context.

Sewers for adoption (WRc 2006), is a guide for the use of developers for provision of sewerage, which could be adopted by all Water Companies in the UK. This document also details requirements for SUDS, so that they can be offered for adoption. However, the institutional responsibility for SUDS in England and Wales has not been defined in this document

The CIRIA SUDS manual (Woods-Ballard *et al.* 2007) provides comprehensive guidance on planning, design, construction and maintenance of SUDS. It also addresses associated issues, such as water quality, quantity, landscaping, biodiversity, public perception, and community involvement, as well as water quality treatment and flood risk management. This is an important document that has added a significantly new level of understanding of SUDS systems.

The issues of water pollution from Roads have been well documented by several studies including (Bastien *et al.* 2010). A more detailed guidance for sustainable drainage associated with roads to mitigate flooding and water quality problems was developed called SUDS for Roads. It is a recent consultation document, intended for use by road engineers within local authorities, Transport Scotland, consulting engineers and other professionals involved in the planning, design, operation and maintenance of roads, surface water drainage and associated SUDS for new and existing developments. The document describes the traditional context of road drainage design and responsibilities of the roads drainage adopting authorities. It fills a significant gap in the understanding of SUDS application to roads. Guidance for construction, operation and maintenance of road SUDS have also been provided in this document. It also describes adoption procedures; from the land-use planning process to road construction consent. Issues relating to un-adopted SUDS and retrofitting are also summarised in the consultation paper (Pittner and Allerton 2009).

2.5 SHIFTING PARADIGMS OF URBAN DRAINAGE

Rapid urban development at the beginning of the 20^{th} century led to the requirement of pipes for keeping cities clean and dry. Surface water and sewage was disposed of into watercourses, causing environmental degradation and diseases for people living downstream. Later, treatment plants were set up, but storm water flows and Combined Sewer Overflow (CSO) spills continued to be discharged into watercourses (Debo and Reese, 2003). As a result, the current drainage systems in urban areas consist mainly of two categories: combined sewers (carrying both foul and storm water) and separate sewers (separate conduits for storm water and foul water). This approach helps in the management of water locally, but it creates flooding in downstream areas as well as water quality problems in the watercourses. In recent years, however, there has been a new trend for managing storm water at a catchment scale using SUDS techniques (Butler and Davies 1998) but the government policies for implementing a broader range of adaptation measures might be hampered by institutional cultures formed when engineered approaches were the norm (Harries and Penning-Rowsell, 2010).

Studies carried out in different places have shown that an approach involving non-structural measures is more sustainable for the management of flooding (Tucci and Villanueva 1999; Faisal *et al.* 1999; Oliveri and Santoro 2000). The measures include: source control (watershed/landscape structure management), laws and regulations (including zoning), economic instruments, an efficient flood forecast-warning system, a system of flood risk assessment, awareness raising, flood-related data bases, etc (Kundzewicz 2009).

Various studies have argued that the development of traditional drainage systems directly harms the surrounding environment. For example, the degradation of water quality and changes in hydrologic response in impervious areas has caused deterioration of ecology and habitat (Walsh et al. 2005). Additionally, watercourse corridors provide a link for dispersal of species (Cook 2002), but developments in buffer areas have caused fragmentation of green spaces leading to further loss of biodiversity (Cairns 1995). Walsh (2004) suggests that direct connection of impervious areas with pipes to the watercourse is harmful to taxa, but this harm could be reduced by applying SUDS for protection of stream biota.

As a result, SUDS systems were introduced to mimic natural drainage and overcome the limitations of traditional drainage. They utilise the concept of "management train", which is a useful concept in the development of drainage systems. This involves using drainage techniques to change the flow and quality characteristics in stages. The storm water management hierarchy starts with prevention, which requires good housekeeping to prevent pollutants from mixing with storm-water runoff. When runoff is generated, it should be controlled at source as much as possible. Site and regional controls involve management of runoff from several sub-catchments. However, as a general principle, the runoff should be controlled as close to the source as possible (Woods-Ballard *et al.* 2007).

In the UK, several projects demonstrate the benefits of SUDS flow attenuation and water quality treatment (Heal and Drai 2003). There are examples of more sustainable approaches to storm water management, but the conventional hard engineering approach is still dominant (White and Howe 2004). SUDS are now a legislative requirement in Scotland, and all new developments include SUDS as a way to manage water quality and quantity (Scottish Government 2003).

Public perception studies for SUDS schemes by Apostolaki (2007) show that attitudes differ among the public according to site characteristics and are strongly influenced by the aesthetics of the scheme and the amenity benefits provided by the systems. The investigation showed that a large percentage of respondents perceived recreation as one of the most significant benefits of these systems. This clearly indicates a potential linkage of drainage planning with recreational planning, which has been overlooked in the current planning system.

Mitigation of flooding and CSO spills is a priority for existing developments. Little attention has been given to the adoption of SUDS techniques in such situations, as SUDS have been adopted mostly for new developments in the UK. Swan (2003) initially proposed retrofit SUDS and his investigations led to the development of a framework for prioritising retrofit SUDS (retrofitting SUDS refers to applying SUDS in existing developments) in urban areas. However, these studies concentrated on hydraulic factors and not on issues of land availability. Subsequent studies carried out by Broad (2004) identifies land, and land owners' approval, as important requirements in the planning of SUDS.

Investigations by Singh *et al.* (2003) utilised the framework of Swan (2003) for assessing the feasibility of retrofit SUDS in the East End of Glasgow. As a result of the studies, it was found that, apart from the type of impermeable areas and type of SUDS, availability and types of green spaces are important factors for the planning of retrofit SUDS in urban areas.

Retrofit SUDS are becoming increasingly popular in several redevelopment projects. For example, in Malmö, Sweden, a SUDS system was created on an infill development to reduce downstream flooding by managing storm water locally. A fundamental benefit of retrofit SUDS in this project was that it helped in creating a water-based ecosystem, and added aesthetic value to the urban landscape (Niemczynowicz 1999). Numerous SUDS projects have also taken place in the Netherlands, which highlights some of the associated issues. Targets for disconnection were set, frequently proving difficult to meet, which was often due to funding constraints. However, based on knowledge gained from using different techniques, disconnection has been combined with replacement of sewers and building of new roads and houses (Verhoeven and Zuurman 2006).

Retrofitting of SUDS is one method for controlling water pollution in receiving water bodies. This has been demonstrated by retrofitting a storm water outfall with a treatment pond at the Houston Industrial Park in Scotland, which resulted in improvement of quality in receiving water (Heal *et al.* 2005). Additional retrofitting of SUDS upstream of the pond, as recommended by Stovin *et al.* (2007), is likely to further improve the quality of water discharged into the receiving watercourse.

Another important element of urban drainage, frequently not receiving appropriate attention, is urban streams. Streams have been culverted in many of the cities in the UK as a result of urbanisation. Such culverted streams having no meanders, pools or riffles are of little ecological importance as they are constrained by concrete and steel lined channels. Also, these watercourses have little recreational potential as they are cut off from the life of the town, hidden behind fences, placed at the back of buildings and gardens and buried in culverts with no public access (SEPA 2000).

Successful stream rehabilitation, according to Booth *et al.* (2007), requires diagnosis of the causes of degradation, and integrated management to treat the range of ecological stressors. Rehabilitation of streams has various benefits: it helps to restore and create habitats for wildlife, improves the recreational and amenity values of the sites, creates a more natural watercourse and encourages its self-maintaining potential (Nolan and Guthrie 1998).

2.6 GREENSPACE PLANNING ISSUES

There are several issues associated with green space planning that affect the design of urban green spaces. These issues deal with both form and function of green spaces and are discussed in this section.

2.6.1 Green space design issues

Accessibility

Contact with nature is an important aspect of urban quality of life (Comber, Brunsdon, and Green 2008). The percentage of green space inside a one kilometre and a three kilometre radius was shown to have significant implications for perceived better general health. The association was generally present at all degrees of urbanity but was somewhat stronger in lower socio-economic groups (Maas *et al.* 2006). However, people's perception of green spaces also affects the use of green spaces. A study in Bristol found that the accessibility of green spaces was better in more deprived areas, but those residents had more negative perceptions and were less likely to use the green spaces (Jones, Hillsdon, and Coombes 2009).

Natural England (2010b) standards recommend that people living in towns and cities should have:

- an accessible natural green space of at least 2 hectares in size, no more than 300 metres (5 minutes walk) from home
- at least one accessible 20 hectare site within two kilometres of home
- one accessible 100 hectare site within five kilometres of home
- one accessible 500 hectare site within ten kilometres of home
- One hectare of statutory Local Nature Reserve per thousand populations

Measurement of green space accessibility can be carried out in GIS, using network analysis. Network analysis with GIS is useful for solving vehicle routing problems, to find shortest paths or to perform origin destination and optimum route analysis (Bono, Gutierrez 2011). This can answer a range of questions, such as roads and railway lines and facilities (Comber, Brunsdon, and Green 2008).

Attractiveness

Public perception studies by Musacchio and Coulson (2001) show that people are interested in the visual characteristics of landscapes. One of the goals of landscape planning is to enhance the beauty of the landscape (Colvin 1970). Attractiveness is related to the dominant perceptual attributes of the physical features of green space as a whole, taking into account the context of the surroundings (Herzele and Wiedemann 2003). Attractiveness is affected by several aesthetic features of a park, such as the presence of trees, water (e.g. a lake), birds, park maintenance (e.g., irrigated lawns), park size (which, in turn provides variety and opportunities to "lose oneself"), and the availability of amenities such as walking paths (Giles-Corti *et al.* 2005).

Natural views tend to be therapeutic in comparison with other urban scenes. They reduce anxiety and stress levels and positively affect an individual. By contrast, other urban scenes such as road traffic increase anxiety and stress levels (Smardon 1988). Another benefit indicated by Hillsdon *et al.* (2006) is that an attractive green space promotes greater use, thus increasing the physical activity of neighbourhood residents.

Biodiversity

Heterogeneity is a crucial element of the environmental benefits derived from efficient functioning and maintenance of natural systems. Areas with tree cover and an understory of small trees, shrubs and herbs may provide critical habitat for wildlife Flores *et al.* (1998). Research has shown that this also has psychological benefits for humans. Fuller *et al.* (2007) found that the degree of psychological benefit was positively related to the richness of plant species and, to a lesser extent, to birds, where perceived richness corresponded with sampled richness.

In the modern era, policies for biological conservation are based on promoting a separation between humans and nature. Even though some initiatives for biological conservation have been carried out for centuries, such as the creation of protected areas, the idea of a conservation area is recent (de Oliveira 2011). It is increasingly being recognised that biodiversity needs to be promoted in cities, and recently United Nations Environmental Program (UNEP) launched a global partnership for cities and biodiversity, which endorsed a plan of action for sub-national governments, cities and local authorities (UNEP 2010).

The structure and functions of biodiversity are interdependent in an open space system. An extensive open space system is based on strategies that: (1) seek to identify the optimal spatial configuration for a particular landscape, which would enable development and change to occur while maintaining landscape functions at proper or acceptable levels; (2) recognise the potential for development actions to make a positive contribution to landscape function; (3) appreciate and integrate dynamic landscape processes with landscape planning (Ahern 1990).

Sports, recreation, and well-being

People generally go to parks in order to relax in a natural setting. Being in nature also evokes feelings of freedom, fortune, adventure, happiness, unity with self, unity with nature, etc. (Chiesura 2004). A study in England found that neighbourhoods with greater proportions of green space were associated with better health, although the strength of the correlation varied with income levels and deprivation (Greenspace Scotland 2008).

Parks can also make provision for outdoor sports, such as sports pitches, playing fields, golf courses, and other outdoor activities. These often occur within parks, but may be separate, especially in the case of golf courses (Dunnett, Swanwick, and Woolley 2002). Park use affects the perception of park availability and quality, according to research by Ries *et al.* (2009). Green spaces can promote integration of disabled people, as shown in studies in Mainau Park in Germany and in the Pancheiron Project in Switzerland. However, this possibility has not been fully developed because of the lack of optimal service provision and landscape structuring (Nicolè and Seeland 1998).

Community Involvement

Differentiation in social traits is more important than physical park attributes in influencing green space patronage. Community quality factors, such as neighbourhood relationships and concern about the community notably affect the perceived importance of green spaces. Urban green space planning in developing countries could add the social-science dimension to the prevailing emphasis on physical design, with a view to embedding the social life of residents (Lo and Jim 2010). People of different cultures were also found to have different park usage. For example, Latino park users visiting parks in large family groups appropriated more space, often engaging in parties, birthday celebrations, wedding anniversaries and picnics, while Caucasian users visited parks less frequently and were also more likely to visit parks alone (Marcus and Francis 1998).

Evidence suggests that low levels of active transport (human powered forms of travel such as walking and cycling) and physical activity among children in the neighbourhood are associated with a lack of perceived neighbourhood safety (Carver, Timperio and Crawford 2008). Community-led approaches in planning, designing, and ownership of green spaces provide multiple benefits. Such an initiative, called "Doorstep Greens Initiative" in England, has promoted interaction, resource pooling, and planning of community events (Natural England 2010a). Balram and Dragićević (2005), emphasise the importance of citizens' participation in the green space planning process, so that planners can understand the non-economic values that citizens place on urban green spaces.

Health

The characteristics of natural environments can aid recovery from fatigue. Natural scenery tranquillises the mind and yet enlivens it (Kaplan 1995). It also enables physical activity, which has been shown to reduce morbidity and mortality by decreasing heart disease, diabetes, high blood pressure, colon cancer, feelings of depression/anxiety, and obesity; while building and maintaining healthy bones, muscles and joints (Bedimo-Rung, Mowen, and Cohen 2005).

Green spaces can reduce the adverse impacts of stressful life events. It was reported from surveys by Van den Berg *et al.* (2010) that the relationships of stressful life events with number of health complaints and perceived general health were significantly moderated by amount of green space in a 3-km radius. According to another study by Maas *et al.* (2008), less green space in people's environment coincided with feelings of loneliness and with a perceived shortage of social support. On the other hand, with more green spaces, Richardson and Mitchell (2010) found a significant decrease in cardiovascular and respiratory disease mortality rates.

2.6.2 Ecosystem services

The various functions provided by green spaces could be grouped into ecosystem services. Moll and Petit (1994) define an ecosystem as a set of interacting species and their local non-biological environment functioning together to sustain life. Urban green spaces provide various services, such as air filtering, micro-climate regulation, noise reduction, rainwater drainage, sewage treatment, and recreational cultural values (Bolund and Hunhammer 1999). The various elements of the ecosystem providing these services are shown in Table 2-2.

Table 2-2: Ecosystem services from various landscape features in Stockholm (Source: Bolund and Hunhammer 1999)

	Street trees	Parks	Forests	Cultivated lands	Wetlands	Streams
Air filtering	X	X	X	X	X	
Micro-climate regulation	X	X	X	X	X	X
Noise reduction	X	X	X	X	X	
Rainwater Drainage		X	X	X	X	
Sewage treatment					X	
Recreation Cultural values	X			X	X	X

Several authors have attempted to value ecosystem services. Valuing ecosystem services through economic considerations would redress its traditional neglect in policy decisions (Chee 2004). Kumar and Kumar (2008) have discussed the various values provided by ecosystems, such as market value, intrinsic value, existence value, bequest value, present value, option value and quasi-option value. Determination of credible value would strengthen the functioning of markets for them, although such valuation is challenging (Kumar 2005). Loomis *et al.* (2000) demonstrated a public survey valuing the ecosystem services in an impaired river basin. In the UK, the importance of ecosystem services is being increasingly recognised, and DEFRA (2007) has developed an introductory guide to valuing them. These studies indicate that valuation of ecosystem services is developing rapidly and could, in the future, become part of mainstream economics.

2.6.2 Multi-criteria green space evaluation

Land-use planning often involves conflicting demands for uses, but it is important to use a well-informed decision making approach. Gul *et al.* (2006) developed a multi-criteria scoring matrix for urban forests, where recreational, ecological and structure-strengthening indicators were used. Investigations by Gul *et al.* (2006) showed greater weighting for recreational themes than for other themes. A methodology was developed by Schetke and Hasse (2008) to analyse multiple criteria associated with green spaces and town planning to assess social and environmental issues. However, this study was applicable only for cities experiencing population shrinkage.

More weighting has been provided for social factors than ecological issues in most of the studies. For example, investigations by Gul *et al.* (2006) provided greater weightings for recreational factors. Similarly, public perception surveys by Giles-Corti *et al.* (2005) also provided more weighting for recreational factors. Gul *et al.* (2006) assumed the parameters within recreational and ecological themes to be of the same weighting, although an assessment by Giles-Corti *et al.* (2005) provided variable weightings for various parameters.

2.7 INTEGRATION OF WATER PLANNING WITH GREEN SPACE PLANNING

Water is an open system (Dreiseitl *et al.* 2001) dependent on landform and is, therefore, one of the natural processes that cannot be manipulated without harming the natural environment. This implies that SUDS planning would require orienting the urban structure planning process in such a way that the requirements of nature are satisfied without affecting benefits in other areas. In other words, it means planning and designing with nature in order to achieve the aims of the planning process as well as efficient storm drainage. A water sensitive planning approach would, simultaneously and synergistically, serve social, economic and environmental objectives (Carmon and Shamir 2009).

Kaiser (1997) describes some of the requirements and possibilities of best management practices for storm water runoff from the view of ecological town planning. The author investigated the total spectrum of urban planning situations dependent on two variables: The amount of storm water runoff (dependent on the amount of paved surfaces) and the possibility of infiltration (dependent on the amount of green space). In a complementary approach in the context of town planning, Carmon and Shamir (2009) advocate a higher density development as a water sensitive approach, as it serves multiple goals: social (enabling more and better services), economic and environmental (reduced pollution loads). The following figures for the effect of building density on generation of runoff were calculated based on studies in USA: 1 housing unit per acre -530 m^3/ year, 4 units per acre - 175 m^3/year from each unit, and 8 units per acre – 140 m^3/ year (Carmon and Shamir 2009).

In the UK, the sustainable planning guide by the Town and Country Planning Association (TCPA) lays down the importance of biodiversity at different levels, from the doorstep to the larger parks, and also specifies the need for integration with sustainable water systems (TCPA 2004). In order to achieve this integration, the SUDS manual (Woods-Ballard *et al.* 2007) emphasises the need for amenity as a design criteria; however, it does not provide much guidance on how it could be achieved.

Some of the attributes for consideration of good amenity spaces which also integrate storm water system are: usability by community, attractive, interesting and multifunctional. These could be achieved through various options, such as creating destination points, seating areas, and easier accessibility (Echols and Pennypacker 2008a). According to Echols and Pennypacker (2008b), sustainable storm water management techniques are being used for enhancement of the amenity and recreational value of various places in the USA. The authors give several examples: a wetland, an axial bio swale terminating in a flow splitter plaza, and scupper with attached stainless steel salmon silhouettes.

In Malmö, Sweden, all new developments in the city are planned with particular consideration for the drainage of storm-water. Wherever possible, new developments are built up along constructed open-drainage corridors, which are laid out at a very early stage in the planning process. Close co-operation between the different technical departments in the city and the active involvement of the public has proved to be of utmost importance for successful implementation of the concept of sustainable storm water management (Stahre 2002).

Integration of SUDS devices into urban planning

SUDS components have several characteristics that support their integration into urban open space planning. This section describes the characteristics of some of the commonly used SUDS types which could be integrated with green spaces.

Swales are shallow, grassy-lined channels with shallow side-slopes designed for conveyance and infiltration of storm-water. The swales can be designed to integrate with the surrounding landscape. As shown in Figure 2-3 they can be created to form features of the landscaped areas of the site or can be incorporated into ornamental, amenity and screen-planted areas (Environment Agency 2010). To increase infiltration, it may be provided with check dams. Vegetation in the swales acts as a filter, which holds back pollutants as well as treating them. Swales are well suited for highways or residential areas because of their linear runoff (Woods-Ballard *et al.* 2007). Swales can be used as part of low impact developments, and also be profitable for developers as demonstrated in an example from Somerset community, USA where the developers saved $916,382 by using swales and bio-retention cells against conventional drainage (Guillette 2010).

Swales also promote biodiversity in urban areas. Investigations by Kazemia *et al.* (2009) showed a decreasing trend of biodiversity, from bio-retention swales, gardenbed-types, to lawn-type green spaces. This result may imply similar patterns of decreasingly favourable habitat features for species in these landscapes.

Figure 2-3: Swale in Ardler Village, Dundee, UK.

Detention basins treat water by providing sedimentation for pollutants. The hydraulic function of detention basins is to provide temporary above-ground storage for storm-water during rainfall. They are designed to reduce peak flow rates, during storm events, to their pre-development levels (Woods-Ballard *et al.* 2007). Detention basins if designed improperly quite often become disruptive wastes of urban land. The basins, which are designed mainly for storm water control without other social benefits, are likely to become intrusions in the lives of urban communities. Urban residents recognise such basins as irrelevant or hazardous to their well-being and have no motivation to maintain them (Ferguson 1991). However, it is possible to mould storm water basins into integrated components of the urban landscape in ways that provide aesthetic, recreational, economic, and ecological values. Evangelisti (2003) presents an example of an integrated basin within a housing estate, which is attractive and accessible, shown in Figure 2-4.

The value of detention basins depends on the associated amenity and aesthetics. This was evident from a residential property purchase survey by Emmerling-Di-Novo (2007), which indicated a preference for properties overlooking wet detention basins over dry ones when people were given a choice. Additionally, investigations by Lee and Li (2009), using the hedonic pricing model, showed that a multi-use detention basin neighbourhood was more highly valued than a single use flood control detention basin neighbourhood.

Figure 2-4: Amphitheatre-Type Detention Basin in the city of Perth, Australia
(Source: Evangelisti, 2003)

Ponds are structures designed for storage of rain runoff during wet-weather. Ponds contain a permanent pool of water and possess additional capacity for attenuation of storm water runoff. They include balancing and attenuation ponds, flood storage reservoirs, lagoons, retention ponds and wetlands (Woods-Ballard *et al.* 2007). The ponds should also have recreational and community uses. Ponds develop a variety of flora and fauna as they contain water all year round. They also provide passive biological treatment for pollutants, as well as sedimentation and filtration (Greenway 2000). Comparative studies of SUDS ponds with natural ponds show that SUDS ponds exhibit similar variability in invertebrate community composition and structure. These similar community compositions and structures suggest that a highway SUDS pond contribute to the biodiversity of the pond network at a regional scale (Viol *et al.* 2009).

In the UK, awareness of habitats provided by SUDS is increasing. Biggs *et al.* (2000) contend that ponds are very rich habitats for aquatic plants, invertebrates and amphibians. They also support a variety of mammals, birds and fish, especially where they form a mosaic of habitats. Many of these species have been identified in SUDS ponds during surveys in the DEX ponds of Scotland (Heal 2010). However, in order to maximise the biodiversity potential of ponds, good design approaches are required, such as proximity to other water bodies like streams or wetlands, shallow waters, undulating topography, islands in larger ponds and planting of native species (Biggs *et al.* 2000).

Past planning and development of green spaces often resulted in development of patches of green spaces and, hence, environmental degradation; and flooding problems could not be contained. However, recent developments indicate that awareness of water sensitive green space planning is increasing. For example, one of the important elements of Glasgow Strategic Drainage Plan is to develop SUDS and deculvert watercourses to reduce flooding (Aukerman *et al.* 2008).

SUDS are becoming recognised as instruments for provision of ecosystem services in urban areas. Jackson and Boutle (2008) have advocated that SUDS should be valued, not just as engineered solutions to mitigate development effects, but also as ecosystem services providing ecological goods. Among the various water features examined by Bolund and Hunhammer (1999), wetlands were found to provide maximum ecosystem services.

2.8 RESEARCH POTENTIAL

This section evaluates the gaps in the existing approaches and recommends an integrated methodology to overcome the existing shortcomings of the various planning approaches.

2.8.1 Need for further research

This chapter has developed the linkages of green space planning and water planning. With the emergence of SUDS as replacements for conventional drainage systems, the importance of amenity and biodiversity in drainage has been highlighted as they occupy one side of the SUDS triangle (CIRIA 2000). As storm water systems become available on the surface, people's perceptions are becoming increasingly relevant. This has been confirmed in various surveys by Apostolaki (2007) and Emmerling-DiNovo (2007), which show preferences for ecologically established and high amenity SUDS systems. However, the degree of integrated planning of SUDS differs in different regions of the world, as discussed in the examples of integrated planning in section 2.6.

Legislation does not provide a framework for integration, as discussed in section 2.3. Planning Policy Statement 25 (PPS 25) focuses only on flood management, with no reference to other aspects of the environment, such as ecology and biodiversity. The WEWS Act 2003 in Scotland, and Water Environment (Water Framework Directive) (England and Wales) provide some impetus to planning for the higher ecological potential of water, but still fall short of providing guidelines for integrated spatial and water planning.

The shifting paradigms of urban drainage have created the need for interdisciplinary planning for storm water. Storm water is increasingly viewed as a resource rather than earlier perceptions of it being a nuisance (Debo and Resse 2003). Various authors, such as Walsh *et al.* (2005) and Cairns (1995), have advocated the need to link storm water planning with ecological and biodiversity planning.

Although several projects (e.g. Aukerman *et al.* 2008; Stahre 2002) have highlighted the recreational benefits involving SUDS, there has not been enough work done to link those aspects with engineering aspects of drainage planning. However, there is a considerable lack of research into the development of a joint methodology to integrate the planning of SUDS and green spaces. This research aims to fill some of that gap by developing a methodology for the integrated planning of green spaces and SUDS.

Through literature reviews it has been found that research and development of SUDS is a recent phenomenon, occurring within the last two decades in the UK. The planning benefits of SUDS and watercourses have come to light through the works of Evangelisti (2003), Whalley (1998) and Apostolaki (2007) among others, as discussed in Chapter 2. However, these investigations present only specific planning aspects of SUDS, and not empirical methods for the integrated planning of schemes.

Previous research, however, has not informed development of the method to determine the overlap of green space planning and water management planning. Perception surveys conducted by Apostolaki (2007) showed the recreational importance people attach towards SUDS and watercourses in the UK and Greece, although these factors were not considered in the initial planning and design of SUDS. Evangelisti (2003) has designed storm water management features involving multiple use facilities, the work was based on individual site considerations and does not describe empirical considerations in planning and design.

Dunnett, Swanwick, and Woolley (2002) describe the recreational aspects of green space planning, which is based on extensive research carried out in green spaces in various locations of the UK. Comparing and interpreting the works of all these authors led to the development of planning parameters for the integrated planning of storm-water and green spaces as part of this research.

There is a need for some enhancement of the understanding of SUDS in the realms of green space planning. It is clear from section 2.7 that SUDS provide various benefits associated with urban green spaces. However, the work by various authors, such as Apostolaki (2007), Emmerling-DiNovo (2007), Jackson and Boutle (2008), Evangelisti (2003), are preliminary and further work is needed to develop a mechanism for an integrated planning approach. The current approach to planning of SUDS suffers from lack of sufficient recreational and amenity planning aspects, as it is focused mostly on hydraulic and water quality aspects. This may be due to the fact that the development of SUDS itself is a new phenomenon and is still rolling out, even in developed countries.

2.8.2 Potential research area

The previous section illustrated that there is a need for further research as there is a gap in knowledge for integrated green space and storm water planning. Therefore, as part of this research, a conceptual framework has been be developed through which integrated planning can be achieved. This framework links catchment level flood planning with green space planning. The integrated methodology includes assessment for water parameters, such as return periods, topography, flood plains and green space parameters, such as enhancement of access, recreation and amenities.

The gaps at institutional levels would also be addressed by the proposed framework. The functions of environmental planning, leisure planning and developmental planning are carried out, according to town and country planning legislation, by various departments within the planning authority; and the road to sustainable planning often has potential for conflicts (Owens 1994). This framework would also identify the interactions between these competing forces to develop an integrated approach to green space and storm water planning.

The value of green spaces is increasingly being recognised for providing ecosystem services. However, further studies have been carried out as part of this research to understand and evaluate the types of services offered by SUDS especially with regards to recreational aspects. In effect, this research would further strengthen the links between water planning and green space planning.

Another gap in existing knowledge was the lack of an integrated evaluation tool which could apply both to green space planning and water planning using a set of indicators from both disciplines. This kind of tool would help the planners and engineers to evaluate various integrated solutions and provide opportunities to maximise the benefits of both areas. This tool has been developed as part of this research and is discussed in Chapter 4. This tool will be part of the integrated green space and water planning framework described in Chapter 3.

2.9 CONCLUSIONS OF LITERATURE REVIEW

This section presents the key elements of the literature and justifications both for the study and the novelty of approach.

- Spatial planning is a complex area which involves balancing the requirements of various land uses such as residential, commercial, industrial, transportation and green space. Town and country planning legislations and other regulations have evolved over the past decades to deal with new requirements of planning.

As a result of increasing urbanisation, flooding has become increasingly severe in recent years as discussed in section 2.2.

- The Flood Risk Management (Scotland) Act 2009 and the Water and Flood Management Act 2010 have been framed in Scotland and England respectively which have improved the institutional framework to deal with flooding. SUDS have been recommended where practicable for new developments as part of this legislation.
- The discussion on green spaces in section 2.6 showed that they provided multiple-recreational and environmental benefits such as aesthetics, places for sports, health, biodiversity and ecosystem services. Although many authors have noted the recreational benefits of SUDS, there was a lack of a framework which could be useful in the planning of their recreational aspects. SUDS provide many similar benefits as green spaces and this research develops a novel framework for integrating SUDS devices with green space planning.
- The water quality and quantity aspects of SUDS have been extensively studied and are part of the design guidance as discussed in this chapter. The recreational benefits of SUDS have also been acknowledged as discussed in section 2.7. However, no evaluation tool has been developed which could be used to integrate the aspects of storm water management and recreational potential. A novel tool which uses both recreational and storm water management indicators is consequently valid.

3 PROPOSED FRAMEWORK FOR INTEGRATED WATER AND OPEN SPACE PLANNING

3.1 INTRODUCTION

This chapter presents a conceptual framework for water sensitive spatial planning in the UK. The proposed framework, outlined in this chapter, will help develop the processes of integrating green space planning and water planning. The framework evolved to address the gaps in current approaches to integrated open space and water planning identified in Chapter 2, as well as from the preliminary study in the east end of Glasgow presented in Chapter 5. The methodology associated with various stages of the framework is presented in Chapter 4.

The overall framework, comprising six stages, (described in section 3.2) is presented in a logical order so that the interdisciplinary steps can be understood and applied in an appropriate manner. The various steps involved in the framework are presented with the help of flow charts to visually link them. The rationale behind the conceptual framework is presented in section 3.3.

3.2 FRAMEWORK FOR INTEGRATED GREEN SPACE AND WATER PLANNING

The integrated methodology was developed by combining knowledge from both drainage and spatial planning sources and synthesising a new integrated methodology with features of both. The sources of information considered for this purpose included research, legislation and guidance on SUDS, flooding, overall spatial planning, and green space planning. The rationale for the conceptual framework is discussed in section 3.3.

This is a conceptual planning framework that can be applied at the preliminary stage of the planning process. It combines elements of drainage planning and spatial planning to develop integrated water and open space plan. Once a preliminary integrated plan is developed, detailed design of urban spaces can be carried out following the principles of the individual disciplines. The scope of this framework ends with the development of the preliminary integrated plan.

The overall framework consists of six stages.

- Stage 1. The study catchment is selected and then initial drainage and land use assessment is carried out.
- Stage 2. Hydraulic assessment of the catchment is conducted in Stage 2 to understand the flooding problems at various locations.
- Stage 3. Open spaces and their potential for SUDS are assessed in the catchment.
- Stage 4. Options for SUDS incorporating both storm water and recreational aspects are developed.
- Stage 5. Hydraulic evaluation of SUDS options.
- Stage 6. The preferred option is selected, based on the integrated evaluation process.

The overall framework (Figure 3-1) represents an innovative approach to integrating recreational planning with storm water management. In particular three stages: stage 3, stage 4 and stage 6 are novel approaches adopted in this framework. Although, existing approaches to planning SUDS such as CIRIA (2000) and Woods-Ballard *et al.* (2007) do recommend the importance of aesthetics and proper landscaping, they do not provide guidance on integrating SUDS with the existing green spaces. Stage 3 of the proposed framework investigates possibilities of SUDS whilst also linking them with the existing green spaces. The recommendations in stage 4 for a detailed set of recreational indicators and attributes are also novel as existing approaches addressed only a limited range of issues such as aesthetic, safety, and vegetation. Although, the recreational indicators currently exist mainly for the planning of green spaces, this research has interpreted these indicators for the amenity requirements of SUDS. The importance of these indicators for SUDS was then verified using a focus group survey (discussed in chapter 4). Further, apart from recreational criteria it also used existing storm water management methods from DEFRA (2005) which could be useful in developing integrated SUDS options. Quantitative scoring system was also developed (in stage 6) using survey results from an expert focus group survey unlike existing approaches which are mainly qualitative in nature.

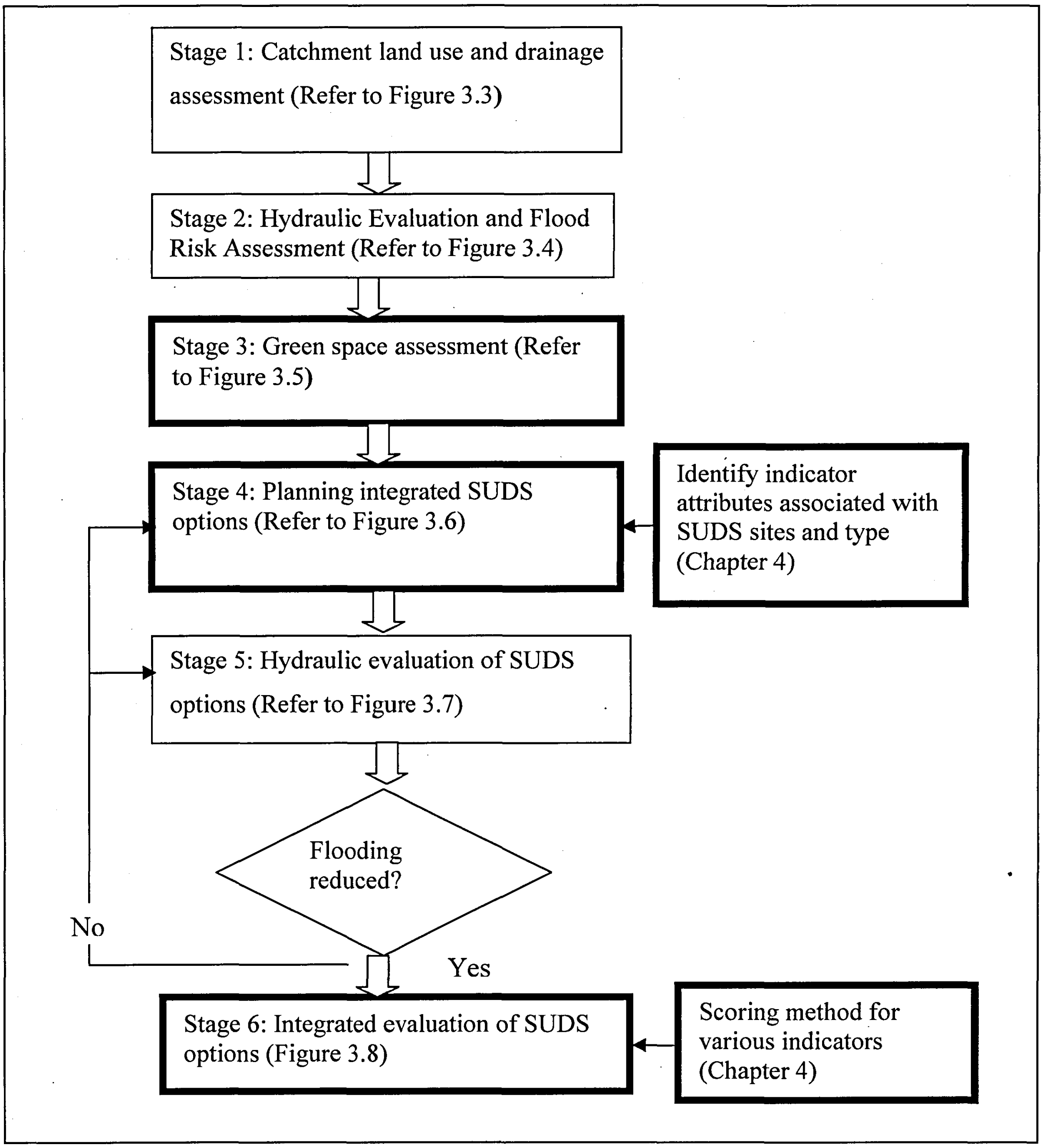


Figure 3-1: Proposed framework for integrated green space and water planning

(Note: Bold boundaries indicate novel approaches adopted)

Being an interdisciplinary framework, it requires both planners and engineers for proper implementation of the various stages, as shown in Figure 3-2. Stages 1, 3, 4, and 6 need both engineers and planners as elements of both spatial and hydraulic planning are involved. For hydraulic assessment and modelling in Stage 2 and Stage 5, only engineers are required and the results need to be communicated to the planners at a subsequent stage. The interaction of planners and engineers between the various stages, and within each stage, is explained in detail in the relevant section. Planners and engineers are associated with various other groups as they receive inputs from various stakeholders such as housing associations, environmental regulators, businesses and various other interest groups. Therefore this approach is linked with wider communities and is likely to result in development of more widely acceptable solutions.

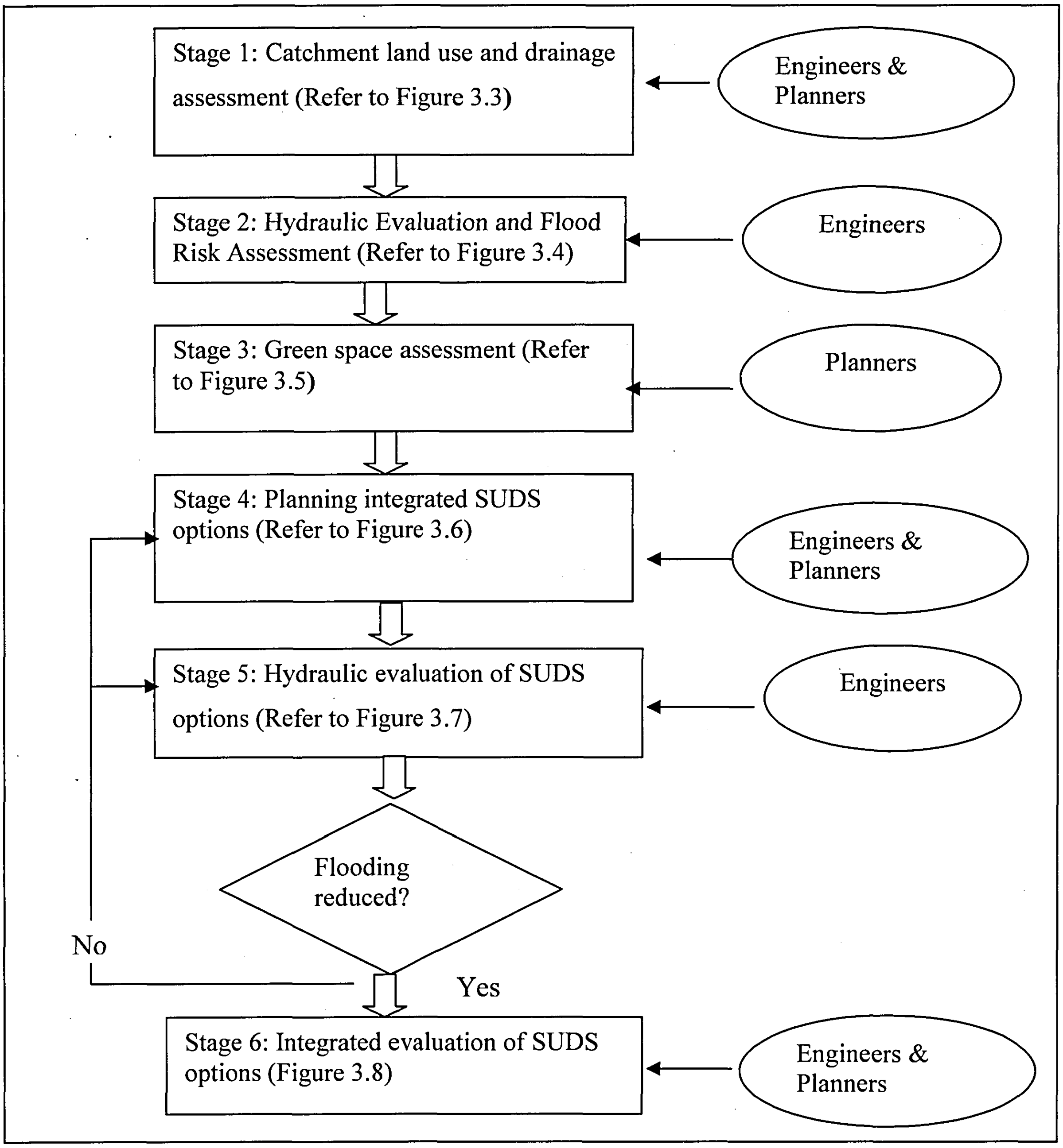


Figure 3-2: Involvement of professionals from multiple disciplines at various stages in the integrated green space and water planning framework

STAGE 1: CATCHMENT LAND USE AND DRAINAGE ASSESSMENT

This stage identifies the flooding and planning issues in a study catchment. It has two components- spatial planning and drainage planning. The spatial plan is informed by Local or City Plan while drainage planning is linked to Surface Water Management Plan (SWMP). Both drainage and spatial planning information is collected and analysed to understand the potential of integrated planning in an urban area. A joint team of engineers and planners is needed to link the planning and drainage analysis as described in the steps below. A flowchart for the steps involved is provided in Figure 3-3.

The various catchment related information was available from the local authorities as they are required to develop SWMPs as part of the Flood Risk Management (Scotland) Act 2009 and Flood and water management act 2010 (OPSI 2009; OPSI 2010). The selected catchments also had green spaces, such as parks and amenity areas, for potential storm water management use.

Step 1a Demarcate catchment and sub-catchment boundaries

A catchment with a flooding problem and a need for drainage improvements was identified from previous flooding records, which was obtained from local authorities. Within the catchment, the sub-catchments were demarcated using topographic and drainage network data from water utility. This step will mainly involve drainage engineers; however, planners may also be consulted to determine additional planning priorities.

Step 1b Study catchment characteristics

Once the catchment and sub-catchments have been identified, catchment characteristics were determined. This involved analysis of drainage networks, such as combined sewer and separate sewers and watercourse drained areas using data with the water utilities and local authorities. Additionally, areas with flooding are identified using flood registers with Local Authority as well as records with other agencies such as Water Utilities, Environment Agency (SEPA in Scotland).

Step 1c: Study land use characteristics

The character of the area was studied to understand the type and configuration of land use, planning objectives and flooding issues arising from it. Planning assessments were driven by considerations of the planning legislation on a number of issues: sustainable development, housing, economic growth, recreation and flooding, as reviewed in Chapter 2. Integrated storm water and green space planning requires identification of drainage patterns, which is carried out in the next step.

Step 1d: Drainage patterns in selected catchments

Within the catchment, initially some sub-catchments were selected for detailed planning of SUDS. If adequate flood mitigation is not achieved (will be shown by comparative hydrographs in Stage 5) then more sub-catchments will need to be selected for additional SUDS. An incremental approach is recommended so that expenditure is curtailed as much as possible. The detailed analyses of selected sub-catchments were helpful in planning options for SUDS in Stage 4. These sub-catchments should be upstream of flood locations and have green spaces for integrated storm water planning. Drainage issues including runoff generation, discharge routes, CSOs, are considered in detail for the sub-catchments selected.

Step 1e: Study detailed land use characteristics in selected sub-catchments

Land use characteristics for the selected sub-catchments were then studied in detail. The investigation includes distribution of green spaces, configuration of development areas, areas for new developments and regeneration areas. Planners from local authorities provided this information, which was then processed to determine the proportions of various land use categories.

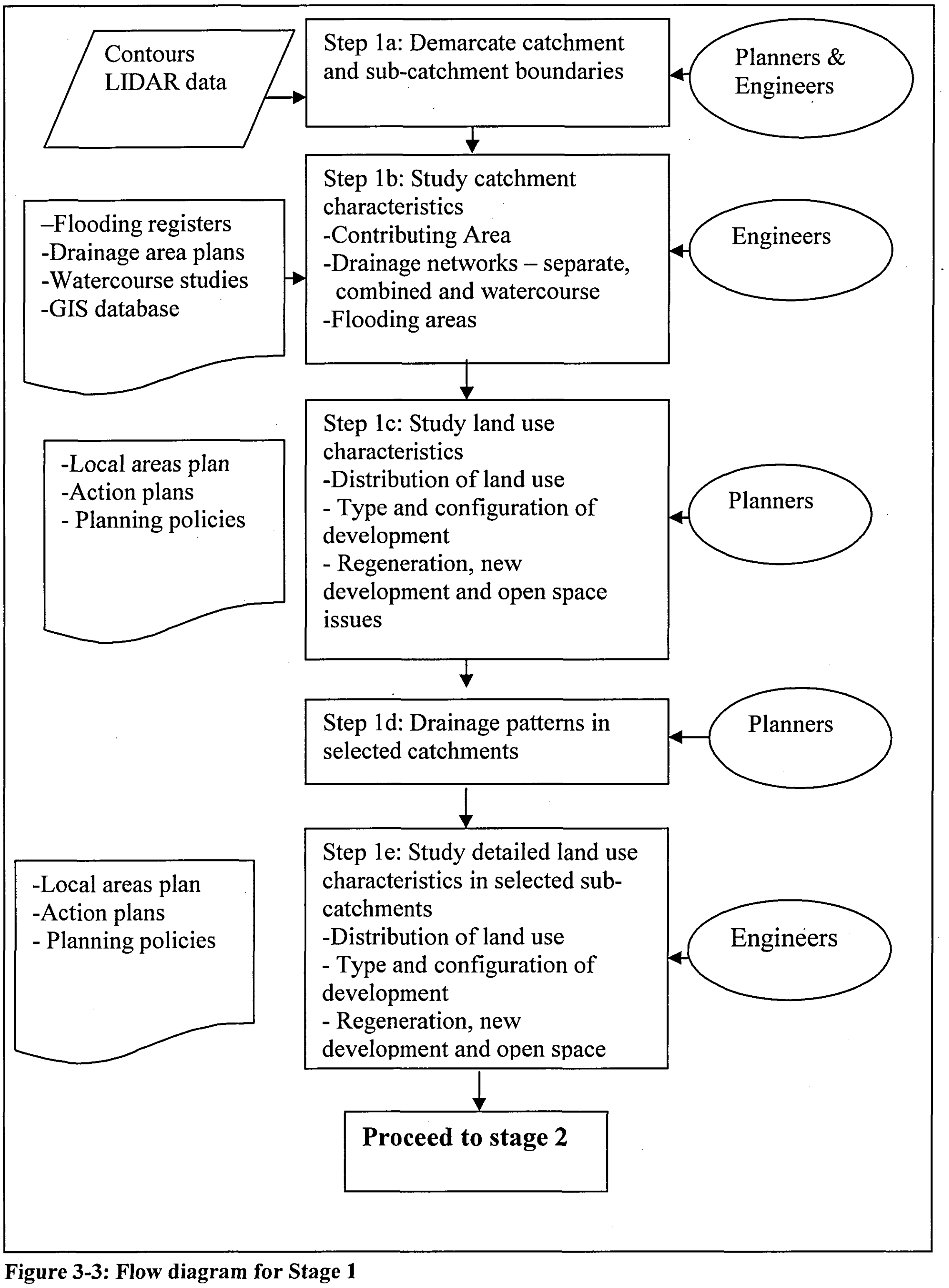


Figure 3-3: Flow diagram for Stage 1

STAGE 2: HYDRAULIC EVALUATION AND FLOOD RISK ASSESSMENT

This stage would inform the SWMPs to be developed as required by the Flood Risk Management (Scotland) Act 2009 and Flood and Water Management Act 2010 (OPSI 2009; OPSI 2010). Assessment of the risk of flooding was carried out using a hydraulic model which contained the network data of both the watercourse and the sewer system. A flowchart for the steps involved is provided in Figure 3-4.

There were three steps involved in this stage.

Step 2a Develop integrated hydraulic model

An integrated model was developed, comprising sewer, watercourse and other drainage routes in the study catchment. A detailed methodology for development of sewer models is provided by the Sewer Rehabilitation Manual (WRc 2001) and was used for the purpose. The development of the model required several types of data which are detailed in chapter 4.

Step 2b Analyse flooding from extreme events

An assessment is needed by civil engineers through detailed analysis of flooding and its influence on current developments. Several extreme events were analysed to determine the causes of flooding. The flooding generated at various sites in the selected subcatchments was identified. Then the vulnerability of the flooding areas were analysed as described in step 2c.

Step 2c: Assess vulnerability of areas to sewer flooding as well as overland flow

Assessment of the vulnerability of the areas subjected to flooding was assessed based on the criteria of PPS 25 or SPP. PPS 25 classifies development into five categories:

- Essential infrastructure. This includes transport infrastructure, power stations and water treatment works
- Highly vulnerable. This category includes police stations, ambulance stations, fire stations, command centres and telecommunication installations.

- More vulnerable. Hospitals, residential institutions (e.g. Care homes, social service homes, prisons and hostels), dwellings houses, student halls of residences, drinking places, hotels, non residential uses of health services, nurseries and educational establishments, and landfill sites are categorised as more vulnerable.
- Less vulnerable. Buildings used for shops, financial, professional and other services, restaurant and cafes, land and buildings used for agriculture, waste treatment except landfills are classified as less vulnerable.
- Water compatible developments. This includes flood control infrastructure, water transmission infrastructure, sewage transmission infrastructure, pumping stations, sand and gravel workings, docks, marinas and wharves, navigation facilities, water based recreation, lifeguard and coastguard stations, amenity option space, nature conservation and biodiversity, outdoor sports and recreation.

These five categories were used to assess the vulnerability of various locations in the study catchments.

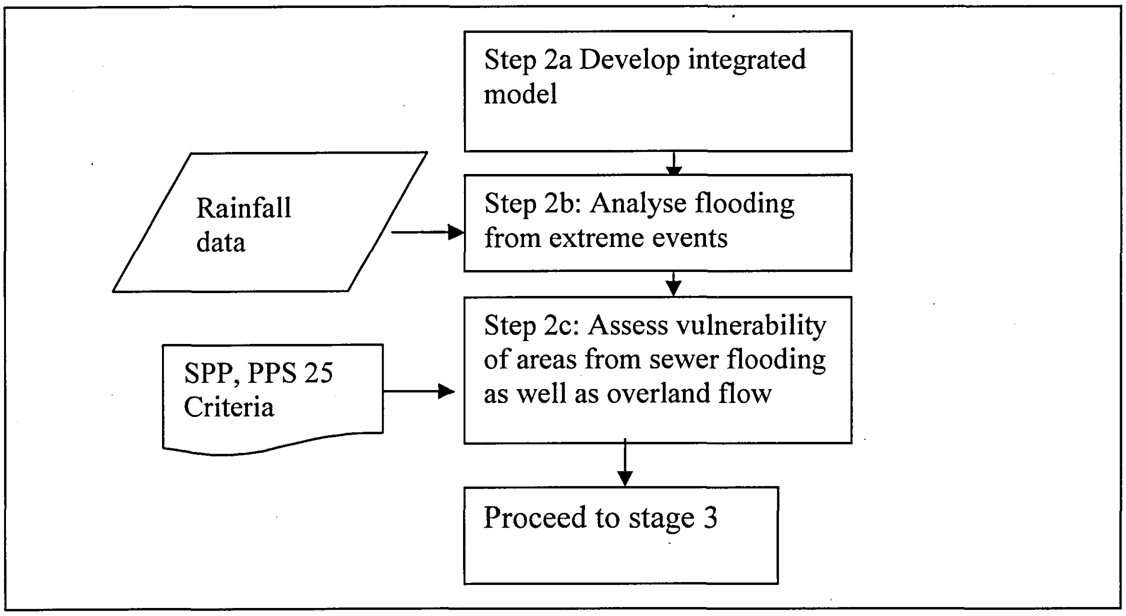


Figure 3-4: Flow diagram for Stage 2

STAGE 3: GREEN SPACE ASSESSMENT

Planning policy statement 8 (PPS 8) associated with open space, sport and outdoor recreation is the main driver for this stage. It further links green spaces with potential for SUDS.

The quantity and distribution of various types of green spaces were identified for location of SUDS at this stage. A flowchart for the steps involved is provided in Figure 3-4.

Step 3a: Categorise green spaces

Initially, open spaces and their various categories were identified in the catchment in the development of a green space plan. Dunnett *et al.* (2002) describes the various categories of open spaces (Table 2-1), which was used for categorisation of open spaces in the study areas. During later stages of the framework, these open spaces were further investigated for their potential for integration of storm water management features such as pond and basins. Categorisation is necessary as not all types of green space will be suitable for SUDS implementation.

Step 3b: Analyse green space distribution in detail

A detailed analysis of green space distribution was carried out within selected subcatchments. This investigation included the determination of the proportion and quantity of various green space categories. Knowledge of distribution of green spaces as well as site topography assisted in determining appropriate sites for SUDS in Step 3c.

Step 3c Evaluate green space distribution in relation to water management potential

Green space distribution in the selected sub-catchments was evaluated for the potential for SUDS planning. This step involved determining whether the locations and quantity of green spaces were adequate for planning of SUDS. Although detailed planning of SUDS options were carried out in Stage 4, this step only qualitatively evaluates the potential of green spaces to deliver the dual use of water management and amenity provisioning.

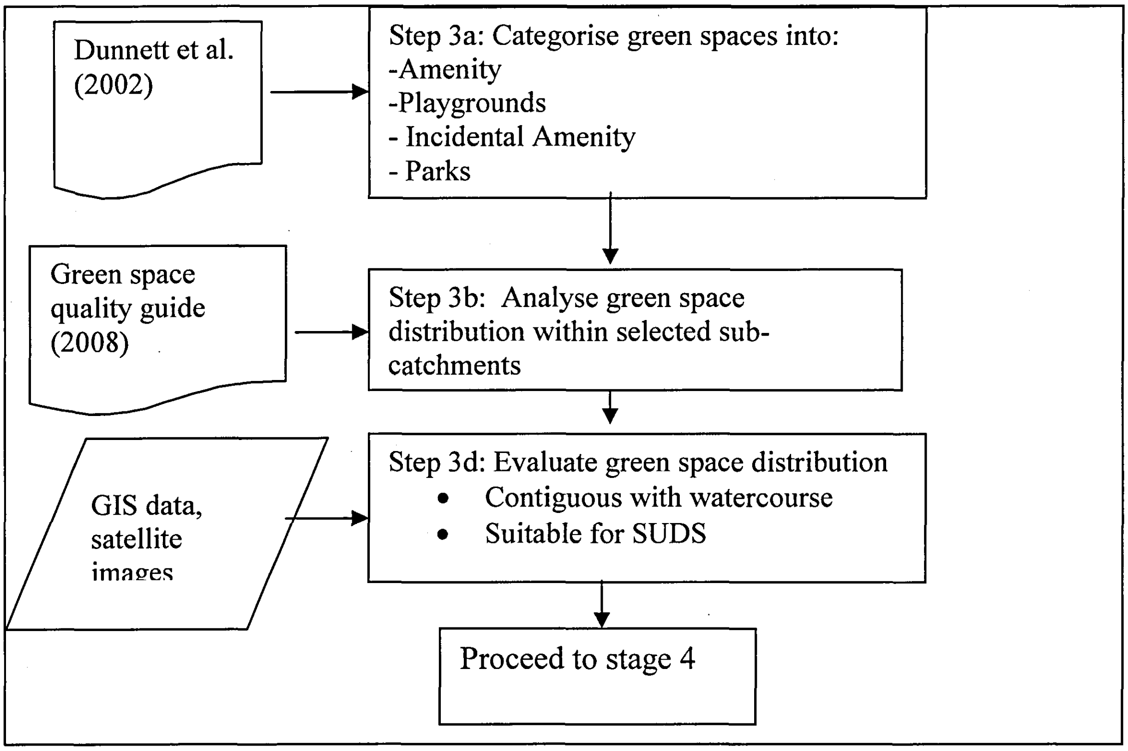


Figure 3-5: Flow diagram for Stage 3

STAGE 4: PLANNING INTEGRATED SUSTAINABLE DRAINAGE OPTIONS

Integrating the green space planning aspects of PPS8 with flood management requirements of PPS 25 or SPP was the main driver of this stage. This stage consists of two steps associated with the planning of two SUDS aspects - storm-water management and recreation. A flowchart for the steps involved is provided in Figure 3-6.

Step 4a Planning SUDS options - Storm water aspects

Based on the various combinations of contributing areas and types of SUDS in a subcatchment, a number of SUDS options were proposed. Various storm water indicators which were considered for planning SUDS are presented in section 4.2. The integrated hydraulic model developed in Stage 2 was used to assess potential sites for attenuation based on the principles from sewer the rehabilitation manual (WRc 2001) and code of modelling (WAPUG 2002). SUDS volumes and areas were determined based on the methodology presented in DEFRA (2005). The storm water indicators (described in section 4.4) were varied to arrive at different options as discussed in section 4.7.

Step 4b Planning SUDS options -Recreational aspects

Recreational aspects of the SUDS sites were identified, using location factors and the type of SUDS option envisaged. The information collected in Stage 3 is useful in analysing recreational opportunities associated with SUDS options. Various recreational indicators related to SUDS are defined in section 4.3 and were used to develop various SUDS options.

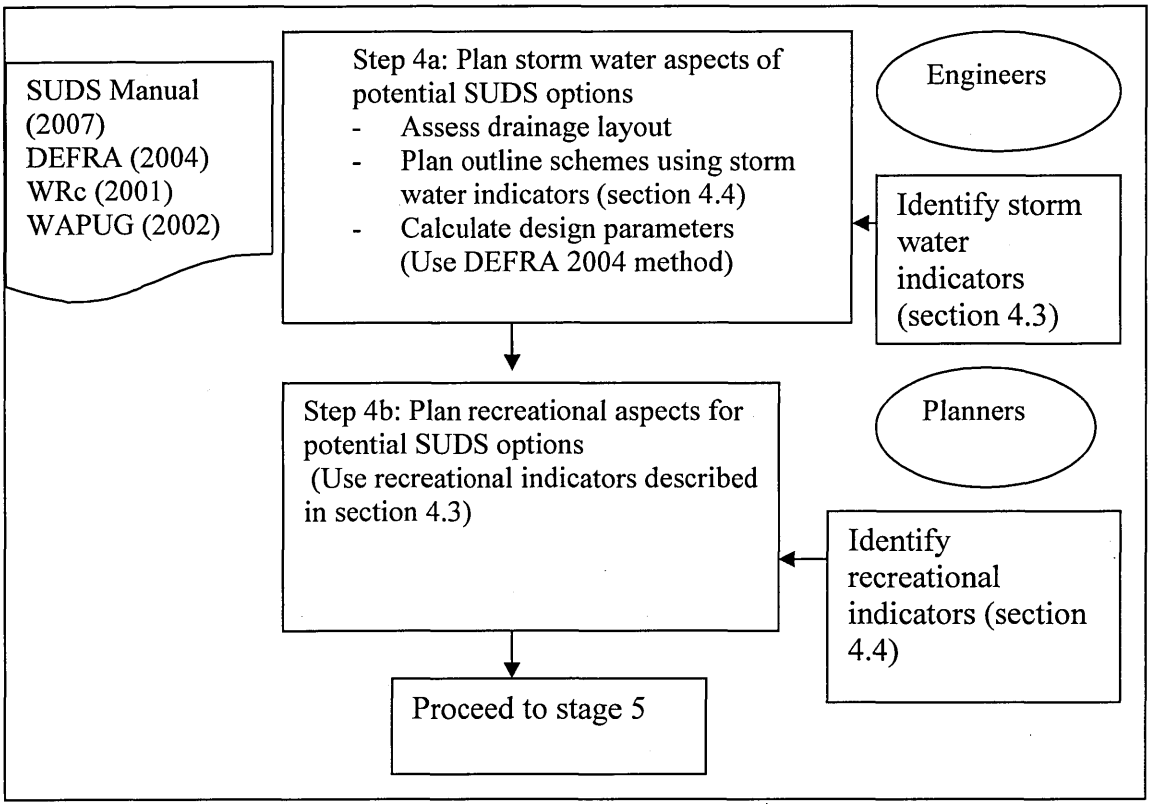


Figure 3-6: Flow diagram for Stage 4

STAGE 5: HYDRAULIC EVALUATION OF SUDS OPTIONS

This stage demonstrates the mitigation of flooding which could informs the SWMPs developed by Local Authorities as part of the Flood and Water Management Act 2010. The modelling approach has been informed by guidance from WAPUG (2002) and DEFRA (2005).

The SUDS options identified in stage 4 were evaluated to assess flood management in the study catchment. The method described here will be used for preliminary evaluation of SUDS and includes determination of contributing areas, SUDS volumes, approximate SUDS locations, inflow and outflow conditions. A more detailed analysis comprising detailed layout of SUDS and pipes of the schemes and costing is recommended when the final option is selected and detailed plan is being developed after a detailed feasibility study but is outside the scope of this research. The detailed feasibility study for any option would also have to take into account the utility drawings, traffic management, locations of architectural buildings in vicinity, CCTV reports of existing sewer network, and detailed survey of the sewer network in the catchment. The steps involved in Stage 5 are presented in Figure 3-7.

Step 5a Model modifications to represent SUDS options

The areas for development of SUDS were identified from Stage 4. The areas were mapped into the model (used in stage 2) using editing tools. In order to represent the effect of SUDS, storage was added to the impermeable areas in the model and the storm water generated from contributing areas disconnected from the combined system.

Step 5b Running simulations

The modified model was run against several design storms of 10, 30 and 200 yr return periods. The critical duration return period was established after examining the flooding from various events of return periods of 15 min, 30 min, 1 hr, 2 hr, 3 hr, 6 hr and 12 hrs. Runoff co-efficient were used based on existing soil type and UCWI was assigned using the FEH data. Simulations were run with a 60 sec time-step and flow hydrographs were determined for the critical events for each SUDS option.

Step 5c Comparison of peak flows of existing and SUDS scenarios

Drainage capacities of sewers from selected sub-catchments were studied to analyse flow and velocity. The new capacity, after installation of SUDS, was compared with the previous capacity to determine their effects. Additional capacity release in the sewers also helped to understand the potential of future developments.

Comparative hydrographs from various SUDS options were developed using the results of simulations. This tested their effectiveness and was also useful to confirm the storm water scores (refer to section4.4) of the integrated evaluation tool as described in stage 6.

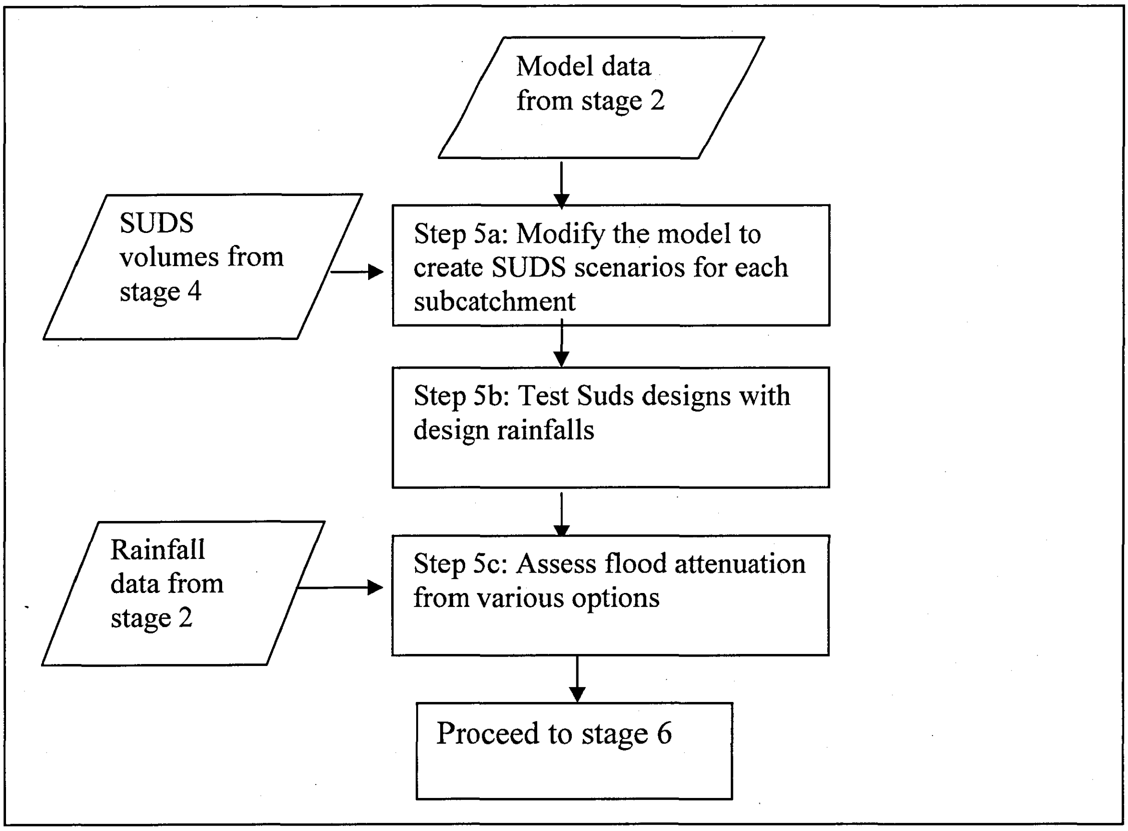


Figure 3-7: Flow diagram for Stage 5

STAGE 6: INTEGRATED EVALUATION OF SUDS OPTIONS

This stage comprises two steps: evaluating integrated options and selecting the final option as described below. This stage integrates the drivers of storm water planning such as PPS 25 with recreational planning such as PPS 8. The steps involved in Stage 6 are presented in Figure 3-8.

Step 6a Scoring of SUDS options

An evaluation of the integrated options is carried out using the integrated evaluation tool developed in chapter 4. This tool contains both storm water and recreational indicators with a simple scoring system (1-3) and weightings (section 4.5) for the various indicators. The tool is useful in comparing total scores accounting for both recreational and storm water aspects associated with SUDS planning.

The tool was developed after reviewing existing knowledge associated with green space and SUDS planning. The objective of the tool was to develop an integrated assessment method for holistic planning of SUDS options as it was concluded in chapter 2 that there was a lack of such a tool.

Step 6b Final proposed SUDS schemes

From comparison of various options in Step 6a, a preferred option is selected. The preferred option is then analysed and discussed among stakeholders such as developers, local authority, and water utility, Environment Agency / Scottish Environment Protection Agency. If agreement can be reached, the preferred option is recommended for implementation, otherwise the next feasible option is recommended.

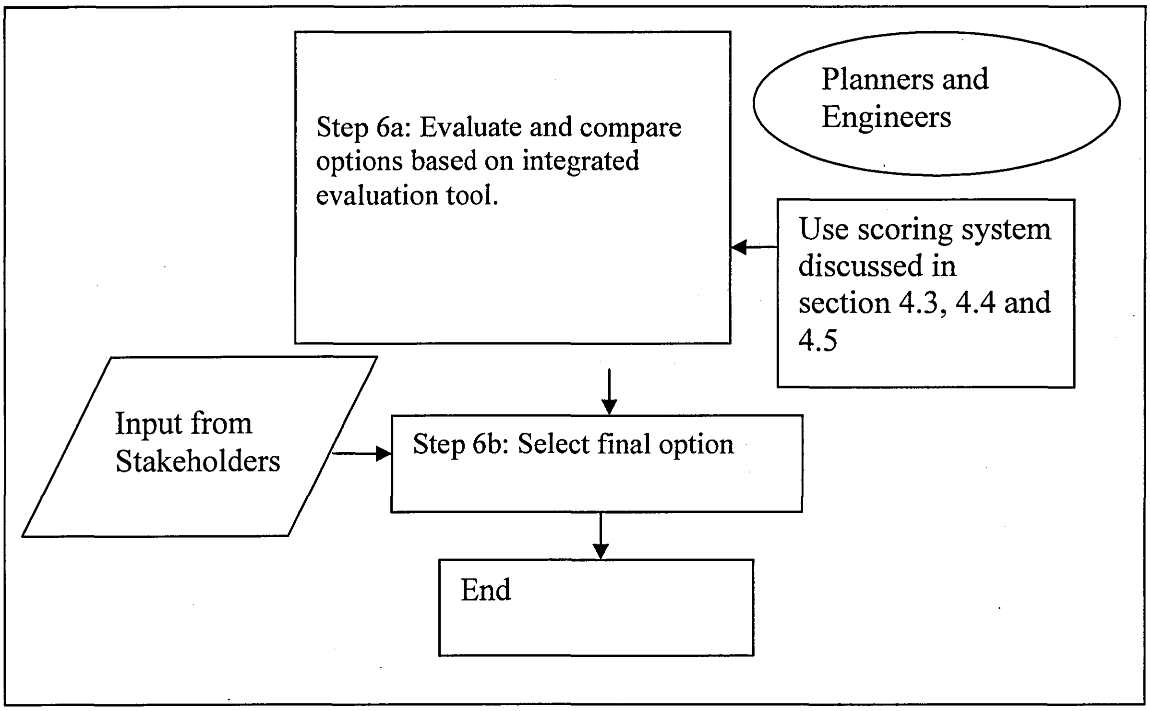


Figure 3-8: **Flow diagram for Stage 6**

3.3 RATIONALE OF THE FRAMEWORK

The research method adopted for this research was utilising a case study to answer the research questions and which seeks a range of different kinds of evidence that is present in the case study setting (Gillham, 2000). As this research required understanding of open space and water planning in the natural setting of a catchment, a case study was perceived as an ideal method to pursue the research. The procedures related to various stages in the framework and their rationale is presented below.

STAGE 1: CATCHMENT LAND USE ASSESSMENT

The purpose of this stage was to link the planning drivers of legislation such as the Town and Country Planning Act (2007); Scotland Planning Act etc (2008) with flood management legislations such as Flood and Water Management Act 2010 and Flood Risk Management Act Scotland (2009). Knowledge of existing drainage patterns and spatial plans provided information to develop integrated understanding of the issues in a catchment.

In stage 1, both spatial planning and drainage planning was considered to enable understanding of relevant constraints and opportunities at the catchment scale. Catchment-based spatial planning was essential as the flooding is linked to development planning and a more holistic planning approach could reduce flooding (Johnson, Penning-Rowsell, and Tapsell, 2007). Identification of the type of drainage system present and areas of flooding facilitated analysis of the modelling of the catchment in stage 2. Additionally, understanding the distribution of development and green spaces was helpful for the identification of areas of recreation and SUDS in stages 3 and 4 respectively, which aid the development of integrated water and green space plans in stage 6.

STAGE 2: HYDRAULIC EVALUATION AND FLOOD RISK ASSESSMENT

Flood management policies such as PPS 25 and SPP were the driver for stage 2. PPS 25 brings a risk based framework for planning of flood management. The policy envisages a source- pathway and receptor model for development planning in flood prone areas. Development of an integrated hydraulic model provided the tool for assessment for the source-pathway receptor model. The hydraulic model would also inform the development of SWMPs by the local authorities which is a requirement of UK flooding legislations such as Water and Flood Management Act (2010) and Flood Risk Management Scotland Act 2009. The method of model assessment and verification was based on the process recommended in the Sewer Rehabilitation Manual (WRc, 2001) and modelling guidelines from WAPUG (2002).

STAGE 3: GREEN SPACE ASSESSMENT

Quantitative assessment was needed to assess the distribution of recreation and amenity functions within urbanised areas. Studies carried out by several authors, such as Apostolaki (2007), Guillette (2010) Evangelisti (2003), indicated that SUDS features can enhance opportunities for recreational and amenity whilst mitigating flooding. It was, therefore, argued that assessment of current recreational and amenity distribution will provide baseline conditions prior to improvement in green space facilities as a result of the potential adoption of SUDS approach. Analysis of green spaces is carried out for sub-catchments using the typology defined by Dunnett *et al.* (2002), i.e. parks, informal recreational areas, playgrounds, incidental amenity areas, and semi-natural green spaces. Other green spaces, such as allotments and burial grounds, are not considered as they are not as common as aforementioned green spaces. Green space standards require greater frequency of formal and informal green spaces in comparison to functional spaces such as allotments and burial grounds (Natural England 2010b). Additionally, it was considered after discussions with local authority officials that use of private green and other functional spaces could face resistance from users.

The assessment at this stage conformed to the requirements of PPS 17 and NPPG 17. These policies specify that local authorities must maintain high quality well managed open spaces, sports and recreational facilities to help create an urban environment that is attractive, clean and safe. Water features such as rivers, streams and ponds are also covered in these policies. Although there is no explicit mention of SUDS the aesthetic planning of SUDS as envisaged in this research would promote the aspirations of PPS 17 and NPPG 17.

STAGE 4: PLANNING INTEGRATED SUSTAINABLE DRAINAGE OPTIONS

Indicators can be useful to represent key information about a subject area in order to evaluate performance (Dale and Beyeler 2001). A set of indicators (shown in Table 3-1) both recreational and storm water were identified after analysing works of various researchers. The indicators were used to integrate some of the recreational aspects of PPS 17 and SPP with storm water management requirements associated with PPS25 and SPP. The development of integrated indicators is described in section 4.2

Table 3-1: Recreational indicators for potential SUDS options

	Indicator	Sources
1	**Accessibility**	Kwana and Weberb (2008)
2	**Water Visibility**	Dunnett, Swanwick, and Woolley (2002)
3	**Aesthetics**	Giles-Corti *et al.* (2005); Smardon (1988)
4	**Passive Security**	Newman (1996); Francis (2003)
5	**Multi-use**	Lee and Li (2009)
6	**Safety**	Apostolaki (2007); CIRIA (2000)
7	**Ownership**	Singh (2003)
8	**Levels of attenuation**	CIRIA (2000)
9	**Attenuation volume**	DEFRA (2005)
10	**Long term storage**	DEFRA (2005); Millerick (2005)

The SUDS sites were assessed in stage 4 using the assessments obtained from first three stages of the methodology:

- Existing patterns of development and drainage infrastructure in the subject catchment as well as flooding records. They assisted in identification of the contributing areas for various SUDS options.
- Flooding sites based on interpreting a verified hydraulic model. The verified hydraulic model more closely simulated the conditions of the existing catchment flooding and its use helped to develop effective schemes for reducing the peak flows in sewers and watercourses.
- Green spaces as well as topographical opportunities of integration. For example, sites which are low lying were good candidates for planning of SUDS.

Although sites are primarily chosen based on hydraulic considerations, the understanding of open space configuration creates opportunities for harmonious integration.

Different indicator attributes were associated with alternative SUDS designs. For example, if water visibility (for amenity value) is an indicator then its presence or absence will be its attribute. Such indicators and attributes were useful for assessing SUDS schemes as previous research has shown. According to Lee and Li (2009) a pond generates greater aesthetic appeal than a detention basin due to the amenity value associated with the presence of water, but will also have higher perceived safety risk due to risk of drowning (Apostolaki 2007). The impact of variations in the attributes of all indicators was assessed in Stage 6 after the assessment of hydraulic impact of each option.

STAGE 5: HYDRAULIC EVALUATION OF SUDS OPTIONS

An evaluation of flood mitigation proposed through the various options generated in the previous stage was the main aim of stage 5. This was carried out by making changes in the hydraulic model developed in stage 2. The theoretical basis for representing attenuation generated by SUDS has been described by research conducted by DEFRA (2005).

Flood related instruments such as Flood and Water Management Act (2010) and Flood Risk Management (Scotland) Act (2009) are the main legislative drivers associated with this stage. Evaluation of the SUDS options can inform the development of storm water management plans by local authorities.

STAGE 6: INTEGRATED EVALUATION OF SUDS OPTIONS

The integrated evaluation tool proposed in stage 6 and further discussed in chapter 4 was used for evaluation of SUDS options. Previously, multi-criteria evaluation systems have been used for assessing diverse requirements of spatial planning. Tools developed for assessing water sensitive urban design (a type of approach to SUDS) used three types of indicators: environmental, engagement and financial (Urrutiagaur *et al.* 2010; Martin *et al.* 2007). However, those tools did not use recreational indicators which are also a major concern of green space planning. The tool proposed as part of this framework utilised recreational and storm water management indicators as discussed in chapter 4. Thus, the benefit of using this tool is that it is at a more detailed level and could be useful for informing decisions for other tools such as the ones by Urrutiagaur *et al.* (2010); Martin *et al.* (2007) which target a higher level planning.

Although, several studies examined the broader social acceptability of SUDS (Apostolaki 2007; Lee and Li 2009) development of scoring of recreational indicators along with storm water management indicators associated with SUDS has not been investigated. Consequently, the focus of stage 6 was to use a scoring system developed as part of this research to evaluate various recreational indicators identified in stage 4. This would bring more objectivity in the planning of recreational aspects of SUDS which so far has been largely subjective. Various considerations associated with the development of the scoring system will be discussed in chapter 4.

This evaluation tool would be useful in assessment of the trade-off between amenity and storm water management and thus produce more holistic solutions than other storm water management approaches (e.g. conventional solutions such as tank sewer, increase of sewer sizes or laying additional sewers) where only storm water aspects were considered.

3.4 DISCUSSION

The proposed conceptual framework has been developed to address the gaps in the existing processes of planning urban drainage. It constitutes various aspects of spatial planning along with storm water planning and thus seeks to develop a more holistic approach.

A research methodology associated with implementing the framework is discussed in chapter 4. The development of an integrated evaluation tool comprising both storm water and recreational indicators introduced in section 3.2 is discussed in detail in sections 4.2 through to section 4.6. A focus group comprising planners and engineers was used to provide weightings to each indicator (section 4.5). Some stages discussed in section 3.2 such as hydraulic evaluation have used existing approaches such as WRc (2001); WAPUG (2002), however other stages (such as stage 1, stage 3, stage 4 and stage 6) use a mixture of existing and novel approaches. The basic principles for implementation of such novel approaches in the framework are illustrated using a theoretical example in section 4.7.

A detailed evaluation of the potential of the framework will be done in chapter 7 after the framework is tested in two catchments discussed in chapters 5 and 6.

4 RESEARCH METHODOLOGY

4.1 INTRODUCTION

This chapter outlines the methodology of the framework adopted for the research. It includes development of integrated indicators, methods for implementing various stages, the strategies for site selection, data collection and analysis. An instrument for evaluation of SUDS schemes, using integrated indicators, is also developed.

The development of integrated indicators is discussed in section 4.2. Recreational indicators are discussed in section 4.3, while storm water indicators are described in section 4.4. In section 4.5, a method of providing weightings to the indicators selected in section 4.3 and 4.5, are described. Section 4.6 discusses a method of scoring the indicators identified in previous sections.

The strategy for the application of the methodology, potential expectations and basic principles are described using theoretical examples in section 4.6. Furthermore, other issues, such as assumptions and limitations of the research approach, are examined in sections 4.7 and 4.8 respectively. Section 4.9 presents the ethical issues associated with this research. A discussion of testing the conceptual framework is presented in section 4.10 which examines practical application issues in case study catchments. The methodology discussed in this chapter has been applied to the two case studies described in Chapters 5 and 6.

4.2 DEVELOPMENT OF INDICATORS

This section deals with development of indicators covering various aspects such as need for indicators, criteria for indicators and types of indicators selected.

Need for indicators

Indicators are useful to represent key information about a subject area in order to evaluate performance (Dale and Beyeler 2001). The indicators associated with drainage planning may belong to different themes. They may be economic (Messner and Meyer 2006), social (Apostolaki 2007), ecological (Robyn *et al.* 2007), water quality (Aranda *et al.* 2006; Sánchez *et al.* 2007). The themes have many overlapping indicators as indicated by several researchers. For example, Robyn *et al.* (2007) states that some ecological indicators have social values as well. Overlapping developmental and ecological aspects have been studied by Paukert *et al.* (2009) which indicates a causal relationship between these two aspects. Through this research, recreational and quantitative aspects of storm water management themes were studied to develop a detailed understanding of the areas through identification of a set of indicators. However, recreational aspects will involve some ecological aspects as well due to the overlaps noted earlier and could be a subject matter of another detailed research.

Criterion for selecting indicators

The indicators being selected are to be used for preliminary evaluation of schemes. They should be:

- Easily identifiable,
- Measurable,
- Should not require detailed knowledge for the subject area.
- Indicator assessment should not be very time consuming.

The above criteria were selected as this methodology is to be used for rapid screening of integrated options and final selection of options based on preliminary but robust assessment.

Recreational Indicators

Amenity aspects have been described as an important part of the SUDS approach (Urrutiagaur *et al.* 2010; Martin *et al.* 2007); however, there has been no established mechanism to study recreational aspects. As same SUDS elements are also part of green spaces, it is assumed that their recreational value will be similar to other green spaces which do not serve the drainage function. For example, a SUDS pond will have similar recreational value associated with a non SUDS pond.

The various recreational indicators are summarised in Table 4-1 below. The listed indicators were selected after considering the criteria for selection for a number of recreational indicators (see section 4-3). Recreational aspects were studied and identified, based on GIS base-map data, visual assessment of the site and the type of SUDS proposed.

Table 4- 1: Recreational parameters for potential SUDS options

	Recreational indicators	Attributes of indicators	Sources
1	**Accessibility**	Footpaths, biking trails, proximity to public transport	Kwana and Weberb (2000)
2	**Water Visibility**	Open water quantity, dry area	Dunnett, Swanwick, and Woolley (2002)
3	**Aesthetics**	maintenance of grass and vegetation and cleanliness	Giles-Corti *et al.* (2005); Smardon (1988)
4	**Passive Security**	Frontage to houses, schools, shops, roads	Newman (1996); Francis (2003)
5	**Multi-use**	Walking, seating, picnic areas, biodiversity	Lee and Li (2009)
6	**Safety**	Risk of drowning	Apostolaki, (2007); CIRIA (2000)
7	**Ownership**	Public, institutional, private	Singh *et al.*(2003)

Storm water Indicators

Alternative designs for potential SUDS consider a range of options based on quantitative variation of attenuation levels and volumes. These variations are created by changing the areas of contributing impermeable surfaces to effect changes in attenuation volume, long term storage volumes and peak flows. For example, in a catchment with 10 ha of impermeable surface area, one SUDS option can be designed to use 5ha contributing area while another option can be designed to use all 10 ha of the impermeable surface area.

Return periods was another indicator as efficacy of flood management would depend on the extent of attenuation of storms of higher return periods. Alternative scenarios with different return period mitigation were considered to assess changes associated with different return periods. For example, 30 yr return period mitigation would provide greater attenuation than 10yrs or 2 yrs. Outline scenarios for planning various storm water aspects (indicated in Table 4-2) were carried out and modelled in stage 5. The boundary conditions for evaluating various storm water indicators are discussed in section 4.4.

Table 4- 2: Quantitative storm water aspects for potential SUDS options

	Storm-water management indicators	Attributes of indicators	Sources
1.	Levels of attenuation	2 yrs, 10yrs, 30yrs	CIRIA (2000)
2.	Attenuation volume	Proportion of area attenuated	DEFRA (2005)
3	Long term storage	Proportion of area attenuated for Long term storage	DEFRA(2005) Millerick (2005)

Evaluation of indicators

Several evaluation methods were examined. Greenspace Scotland (2008) uses a scoring system on a scale of 1 to 5 to assign scores as an example for guidance to develop consistent scoring. Gul *et al.* (2006) divided the indicators developed a scoring system with scores from 1 to 3 as this scale was useful in classification of his survey of indicators into three groups: least important, (1) to most important (3).

For the purpose of this research, a scale of 3 was considered to be appropriate as this will reduce the uncertainty associated in determining the value of a particular indicator. Recreational indicators are associated with values which are abstract, so a smaller scale would increase the confidence in the scores. Furthermore, it is the first attempt at scoring of recreational indicators for SUDS, and there was no past basis for comparisons.

Overall scores will be in the range of 1 to 3, with three being the highest. However, safety indicators should be assessed with negative scores of -1 to -3, the highest being the most negative. The negative scoring for safety risk is due to its negative perception among other indicators. In options where more than one SUDS storage sites are provided, best case recreational factors will be considered. For example, if an option comprises a pond and a detention basin, then the highest score for aesthetics will be provided. However, the safety indicator will be scored for the worst case scenario. Once each indicator has been assigned scores, weightings will be assigned to determine the overall score for each SUDS option. Based on the overall score, the highest scoring option is selected as the preferred option.

4.3 RECREATIONAL INDICATORS FOR SUDS

Several spatial indicators relating to recreational aspects of planning were reviewed to assess their applicability to the planning of SUDS. These indicators are generally associated with recreational and environmental aspects of urban planning. This analysis is presented below.

1. Accessibility.

Kwana and Weberb (2008) define accessibility as a means of modelling the possibilities and limitations on the movements of an individual through space and time. This implies that sites with no access paths have low accessibility while sites with multiple access routes have higher accessibility. Vehicles facilitate access where road network exist (Lambert *et al.* 2010). As SUDS are to be developed for storm water management and amenity purposes, routes for pedestrian and vehicular access is recommended and the following three would appropriately reflect the possibilities and limitations of access to SUDS sites.

- High: Access through roads and footpaths
- Medium: Accessibility of sites will be through formal footpaths only
- Low: Sites with no access paths

2. Water visibility

Water is considered an important ingredient of urban green space. Public perception surveys have shown that the presence of water is considered second in importance for green spaces after vegetation (Dunnett, Swanwick, and Woolley 2002). Apostolaki (2007) showed that ponds were considered more attractive than basins, as ponds have a greater presence of water. Investigations by Emmerling-DiNovo (2007) indicated a public preference for wet detention basins over dry ones, as they were considered to have higher aesthetic value, and that quantity of water could be used as an indicator for recreation.

According to CIRIA (2000), a permanent pool of water is defined in terms of treatment volume (TV), which could be used for classification of the SUDS schemes. The purpose of treatment volume is to provide biological treatment to the storm water flowing into ponds. The treatment volume in ponds could be used to define to extent to water visibility as follows:

- High: This will include schemes such as retention ponds and wetlands
- Medium: This will include ponds, wetlands, and wet basins.
- Low: This includes most of the SUDS types except ponds and wetlands.

3. Aesthetics

Attractiveness is affected by several aesthetic features of green spaces, such as the presence of trees, water (e.g. Ponds), birdlife, maintenance (e.g., irrigated lawns), size, and the availability of amenities such as walking paths (Giles-Corti *et al.* 2005). The aesthetic appeal of vegetation includes structure, form, foliage patterns (Smardon 1988).

Research by Adam *et al.* (1994) showed that for aesthetic appeal, public preference for ponds was higher than that for basins. Similarly, investigations by Emmerling-DiNovo (2007) indicated a higher preference for wet, rather than dry, basins, owing to their aesthetic appeal. Based on these researches it is inferred that the types of vegetation and presence of water was considered for defining aesthetics for SUDS.

The structure of vegetation and presence of water will be considered for evaluating aesthetics of SUDS schemes as they could be easily identified at the planning stage. Maintenance and biodiversity patterns are not identifiable at the initial planning stage and could only be considered at the detailed design stage. In accordance with the selected criteria, the SUDS will be divided into three categories with respect to aesthetics:

- High: SUDS device with presence of water and a variety of vegetation, such as trees, shrubs and ground vegetation
- Medium: SUDS device without water but with a variety of vegetation, such as trees, shrubs and ground vegetation
- Low: SUDS device with only ground vegetation, such as grass

4. Passive security

Crime prevention through urban design is an innovative approach to reducing crime in cities. Clusters of homes surrounding recreational facilities can provide a sense of passive security (Newman 1996); therefore, planning of SUDS in proximity to homes will improve residents' sense of security. Sense of security can also be increased by designing more uses and activities for open spaces, which would increase the number of people present in an area (Francis 2003). There is a perception of safety risk if green spaces are isolated (Luymes and Tamminga 1995); therefore, scoring on passive security is based on the presence of housing close to the SUDS:

- High: SUDS device surrounded by housing on all sides
- Medium: SUDS device with housing on some sides
- Low: Isolated SUDS device

5. Multi-use

Integration of SUDS with other overlapping urban functions is becoming increasingly popular. Investigations by Lee and Li (2009) using the hedonic pricing model, showed that neighbourhoods with a multi-use detention basin were more highly valued than those with a single-use flood control detention basin. Dry basins can be designed to act as playgrounds or sports courts. The basins will be out of use only during periods of heavy rainfall and can be used for sports at other times (Nascimento *et al.* 1999). The integration of sports pitches with flood management has also been identified by Perez-Sauvagnat *et al,* (1998). In addition to multi-purpose basins can also be used as multi-function facilities. Ponds offer a range of amenities, ranging from pond dipping to fishing, and also attract water fowl (Gledhill, James, and Davies 2005). Thus the number of uses or functions defines scoring of this indicator as follows:

- High: Multiple-use (Storage, vegetation, surrounded by play areas and seating)
- Medium: Dual use (Storage and Vegetation)
- Low: Single-use (retention of water only)

6. Safety

A perception of safety hazard is associated with some of the SUDS. Ponds are deemed to be safety hazards for children according to surveys by Apostolaki (2007). Depth of permanent pools of water can be used as an indicator for safety hazards (CIRIA 2000) and therefore most design guidance recommend gradual deepening of ponds. As these sources suggest the importance of depth, it will be used as an indicator to assess the safety hazard associated with a SUDS option.

Three levels of risks are suggested to be evaluated. Dry SUDS such as detention basins and swales would have no risk during most periods due to a lack of a permanent pool of water and hence will be in the low risk category. The second category of medium risk will relate to SUDS with up to 1m depth. This is based on Schwebel *et al.* (2007) who suggest that most young children feel safe in depths of up to 1m of water. SUDS with depth greater than 1m will be in the higher risk category due to greater risk of children drowning. This indicates if depths of water in SUDS are lower there is a higher perception of safety.

- High: This includes the dry SUDS types such as swales, detention basins.
- Medium: This would include ponds and wetlands with depths up to 1m.
- Low: This would include schemes such as retention ponds and wetlands with water depth more than 1 m.

7. Ownership of land

Ownership of land is a relevant factor determining the potential for development of SUDS. Previous studies by Singh (2003) showed that public green spaces are most favourable for SUDS, while private green spaces are least favourable. Institutional areas are in between public and private spaces in terms of favourability for planning of SUDS. Research by Stovin *et al.* (2007) also indicated that planning of SUDS in private properties would be logistically more difficult.

- High: Public ownership of land, such as parks , amenity areas
- Medium: Institutional ownership of land
- Low: Private ownership of land, such as private gardens

4.4 STORM-WATER MANAGEMENT INDICATORS

The selected indicators are aimed at evaluating the mitigation of flooding downstream of a catchment or sub-catchment. Impervious areas in built up catchments change the nature of pre-development runoff, increasing its volume, velocity and peak flow, while reducing interception and infiltration losses leading to downstream flooding (DEFRA 2005). The selected indicators can be used at the initial planning stage to provide attenuation of peak flows.

1. Flood return period

Three types of attenuation measures are defined by CIRIA (2000): source control, site control and regional control. They are designed to mitigate different levels of rainfall probability. Source control is designed to manage runoff up to 2 yrs return period. Site control SUDS are designed to provide attenuation for rainfall return periods up to 10 yrs while regional controls are designed for a return period of up to 30 or 100 yrs (CIRIA 2000).

- High: flood mitigation for up to 30 yrs or more
- Medium: flood management up to 10 yrs
- Low: Flood management up to 2 yrs

2. Attenuation volume

The amount of impervious area also increases the amount of runoff generated due to its area of higher runoff coefficient. The greater the amount of impermeable area draining into a SUDS feature the more will be the attenuation generated in the catchment (DEFRA 2005). Based on this fact, mitigation of the effects of impervious areas would be measured by the proportion of impervious areas draining to the SUDS as follows:

- High: More than two-thirds of impermeable area draining to SUDS
- Medium: Between one-third and two-thirds draining to SUDS
- Low: Less than one-third draining to SUDS

3. Long term volume

Long term storage volume (LTV) refers to storm water drained by infiltration or at flow rates less than 2 litres/s/ha. It aims specifically to address the additional runoff caused by development and reduces the risk of flooding resulting from extreme events (DEFRA 2005). Loss of infiltration caused by development of impermeable surfaces results in higher runoff (Akan and Houghtalen 2003). LTV is required to bring parity between pre-and post development volumes (Millerick 2005). As long term storage is directly proportional to the impermeable area (DEFRA 2005), the amount of impermeable area was being used for evaluation of this indicator as follows:

- High: More than two-thirds of impermeable area draining to LTV
- Medium: Between one-third and two-thirds impermeable area draining to LTV
- Low: Less than one-third impermeable area draining to LTV

4.5 DEVELOPING AN INTEGRATED EVALUATION SYSTEM FOR SUDS OPTIONS

Stage 6 of the proposed framework in Chapter 3 required development of an evaluation system. It was conceived that there would be a scoring system for the indicators which would utilise attribute points. However, the importance of indicators proposed for SUDS needed to be determined and a focus group was proposed for this purpose. The group was also be useful to validate the indicators proposed as part of the instrumentation.

Focus group

A focus group was set up to validate the selection of indicators and assess the importance of indicators identified in section 4.2 and 4.3. The objective of the survey was the following:

- To provide quantitative weightings to reflect the importance of the indicators
- To provide relative weightings for the two themes of planning for storm water management and recreation associated with SUDS
- To understand the reasons behind the weightings provided by the focus group members

The group comprised of professionals of diverse disciplines such as urban planning, engineering, law making, and environmental planning and had both practitioners and academics. This diversity of the group ensured that the opinion obtained was likely to be more objective than the group having members of only one discipline. The members belonged to several regions including Scotland, England and the Netherlands which would make the results of the survey more widely applicable.

A presentation was given to the focus group about the aims and objectives of the research project. The participants were also informed about the various indicators selected as part of the research and their potential benefits in delivering the objectives of the research. Most participants from an engineering background wanted to know and understand more about the recreational aspects of SUDS while participants from non-engineering backgrounds wanted to understand about the engineering aspects. The queries raised by the participants about the research were resolved and questionnaires with three questions were distributed.

The questionnaire (shown in Appendix A1) deals with the first two objectives listed above while personal interviews were conducted to achieve the third objective i.e. to understand the reasons behind the choices of the participants. The first question enquired about the importance they would assign to the two themes of storm water management and recreational opportunities offered by SUDS. The participants were required to score the perceived importance on a scale of ten (1 to 10) for each of the two themes. The second and third questions were designed to gain an understanding of the perceived importance for recreational and storm water management indicators respectively. The participants were required were required to score the perceived importance on a scale of ten (1 to 10) for each of the indicators. The responses of the participants were converted into a scale of 0.1 to 1.0 for convenience and will be used in this section.

Questionnaires were issued to 20 people who were part of the focus group. However, only 17 people returned the filled out questionnaire and three participants out of the seventeen failed to provide the weightings for storm water indicators.

The results of the survey for the first question showed that 5 participants provided equal weightings to both recreational and storm water management indicators. The average score of each theme was close to 0.75 is shown in Table 4-3. Recreational scores provided by the participants showed that more than 40% of the group provided a maximum score of 1 to safety (Refer to Table 4-4). Another 23% provided a score of 0.8 and 0.9 to safety while only 17 percent of the participants gave a score of less than 0.5. Aesthetics and multi-purpose were other indicators which received higher scores than the remaining recreational indicators. The recreational aspects were generally well appreciated by all engineers except one who provided low scores in comparisons to the storm water management aspects.

Weightings for the storm water management indicators were also provided by the participants. Maximum weightings were assigned to flood return period indicator which 4 participants gave a score of 1.0. The other two indicators also received a score higher than 0.5 as shown in Table 4-5.

Individual interviews with survey participants were conducted to understand their perceptions about the indicator scores they provided and their views were similar to the scores provided. The general consensus was that both storm water management and recreational aspects of SUDS are equally important. Safety and multi-use were perceived as the most important recreational indicators, but the potential role of other indicators was also appreciated. However, the planners said that safety becomes an important political issue and should therefore be given a higher weighting.

Obtaining normalised weightings for the indicators

Normalised weightings for recreation and storm water management indicators were obtained using the survey results of the three questions and have been discussed in this section. The weightings assigned to the two themes of recreation and storm water management associated with SUDS (Question 1 of the survey questionnaire) are shown in Table 4-3. Average obtained for each of the themes (Last row of table 1) showed approximately equal importance for both recreation and storm water management.

Table 4- 3: Weightings for the two themes of Recreation and storm water management

Participant No (N)	Recreation, Tr	Storm water management, Ts
1	0.9	0.7
2	0.8	0.9
3	0.75	0.6
4	0.8	0.7
5	0.6	1
6	0.8	0.6
7	0.8	0.8
8	0.7	0.8
9	0.7	0.9
10	1	1
11	0.7	1
12	0.8	0.2
13	0.5	0.5
14	0.9	0.9
15	0.8	0.8
16	0.4	0.8
17	0.7	0.75
$\sum N$=17	$\sum Tr$=12.65	$\sum Ts$=12.95
Average	$\sum Tr / \sum N$ =0.74	$\sum Ts / \sum N$ =0.76

The weightings assigned to proposed recreational indicators (Table 4-4) and the two themes (Table 4-3) were used to determine normalised recreational scores using equation 4.1. The required average indicator weighting for each indicator is shown in the second last row of Table 4-4 while the normalised weightings for each recreational indicator are shown in the last row of the table. As

Weightings assigned to proposed recreational indicators (Table 4-4) storm water management indicators (Table 4-5) and the two themes (Table 4-3) were used to determine normalised weightings for storm water management indicators using equation 4.2. As the total weighting of the storm water management theme was approximately equal to the total weighting provided to recreational theme (second last row of Table 1), the total normalised weighting for the all storm water indicators should be equal to the total normalised weighting for all recreational indicators i.e. $\sum Wnr = \sum Wns$.

Table 4- 4: Weightings for recreational indicators (Wr) provided by the focus group members

Participant No (N)	Access	Water visibility	Aesthetics	Passive security	Multi-use	Safety	Ownership
1	0.8	1	0.9	0.6	0.6	1	0.4
2	0.8	0.9	0.7	0.6	1	0.6	0.6
3	0.5	0.7	0.6	0.5	0.8	0.7	0.6
4	0.8	0.8	0.7	0.3	0.7	1	0.6
5	0.5	0.7	0.7	0.6	0.7	0.9	0.7
6	0.8	0.8	0.7	0.8	0.8	0.9	0.8
7	0.6	0.6	0.8	0.9	0.9	0.9	0.7
8	0.7	0.5	0.7	0.8	0.7	0.5	0.8
9	0.5	0.7	0.7	0.6	0.8	1	0.5
10	0.7	1	1	0.4	0.8	0.4	1
11	0.6	0.8	0.8	0.7	0.8	1	0.8
12	0.7	0.8	0.8	0.8	0.9	1	0.8
13	0.8	0.3	0.8	1	0.8	0.3	0.9
14	0.6	0.4	0.7	0.8	0.8	0.8	1
15	0.9	0.6	0.6	0.8	0.9	1	0.4
16	0.1	0.1	0.8	0.1	0.2	1	0.1
17	0.5	0.75	0.5	0.3	0.8	0.1	0.7
Total, $\sum Wr$	10.9	11.45	12.5	10.6	13	13.1	11.4
Avg, Wri= $\frac{\sum Wr}{\sum N}$	0.6	0.7	0.7	0.6	0.8	0.8	0.7
Normalised Wnr	0.6	0.7	0.7	0.6	0.8	0.8	0.7

$$Wnr = Wri * \frac{\sum Tr}{\sum Ts} \quad \text{....... Eq. 4.1}$$

Where, Wnr is the normalised recreational weighting

As there are only three proposed storm water management indicators in comparison to 7 recreational indicator a factor of $\frac{\sum Wri}{\sum Wsi}$ has been multiplied with $Wsi * \frac{\sum Tr}{\sum Ts}$ so that an equivalent value for each storm water management indicator was obtained. The required weightings for normalised storm water management indicators thus obtained are shown in the last row of Table 4-5.

Table 4- 5: Weightings for storm water indicators (Ws) provided by the focus group members

Participant No. (N)	Flood return period	Attenuation volume	Long term storage
1	1	0.8	0.6
2	-	-	-
3	0.7	0.6	0.7
4	-	-	-
5	0.8	0.7	0.5
6	-	-	-
7	0.8	0.7	0.8
8	0.6	0.6	0.9
9	0.8	0.8	0.7
10	0.8	1	0.8
11	1	0.9	0.8
12	1	0.7	1
13	1	0.3	0.6
14	0.8	0.7	0.8
15	0.6	0.7	0.9
16	0.8	0.5	0.5
17	0.7	0.8	0.4
Total, $\sum Ws$	11.4	9.8	10
Avg, Wsi= $\frac{\sum Ws}{\sum N}$	0.81	0.70	0.71
Normalised, *Wns*	1.7	1.6	1.6

Note: Blank spaces indicate no response from some focus group members

Normalised score is calculated using the following formula:

$$Wns = \frac{\sum Wri}{\sum Wsi} * Wsi * \frac{\sum Tr}{\sum Ts} \quad \text{....... Eq. 4.2}$$

Where, Wns is the normalised storm water weighting

The normalised weightings for indicators associated with both themes of recreation and storm water management have been summarised in Table 4-6. These normalised weightings, in addition to attribute points as discussed in the next section, were used to determine scores of indicators associated with potential SUDS options.

Table 4- 6: Normalised weighting of each indicator

Theme	Indicators	Normalised Weightings, *Wnr Wns*
(1)	(2)	(3)
Recreational Indicators	Access	0.6
	Water visibility	0.7
	Aesthetics	0.7
	passive security	0.6
	Multi-purpose	0.8
	Safety	0.8
	Ownership	0.7
Storm water indicators	Flood return period	1.7
	Attenuation volume	1.6
	Long term storage	1.6

Scoring of indicators

The indicator scores for various SUDS options were obtained based on attribute points as well as the weightings associated with individual indicators. Attribute points were based only on the classification of attribute and were denoted as Ap. They (Ap) were in the range of 1 to 3 where 1 corresponded with low level attributes and 3 were associated with high level attributes. The weightings shown in Table 4 were also used for scoring of indicators. The scores for recreational (Sr) and storm water management (Ss) indicators were calculated using equations 4.3 and 4.4 respectively as shown below.

$$Sr = Wnr * Ap \qquad \text{....... Eq. 4.3}$$

Where,

Sr is the recreational indicator score

Wnr is normalised weighting for recreational indicators

Ap is the attribute point

$$Ss = Wns * Ap \qquad \text{....... Eq. 4.4}$$

Where,

Ss is storm water management score

Wns is normalised weighting for storm water indicators

Ap is the attribute point

4.6 METHODOLOGY FOR APPLICATION OF THE FRAMEWORK

This section describes the procedure for using the framework. The first section presents the generic methodology and describes the data requirements and analysis associated with various stages in the framework. The second subsection describes the basic principles of the methodology using an illustrative example. The third subsection presents a critical appraisal of the methodology

The methodology

This section describes how the conceptual framework developed in chapter 3 and the integrated evaluation tool developed in this chapter was used in a study catchment. It outlines the procedures and processes involved at the various stages and references have been made to illustrative examples in this chapter as well as to the case study example in Chapter 5.

Stage 1

Historical flooding locations in the sub-catchment from records with the local authority or drainage utility were determined. Then, land use characteristics using the GIS base-map were studied. This involved demarcating areas of residential, commercial, open spaces, road networks, institutional areas and any other categories which may exist in the catchment.

Land use was classified into various categories such as residential, institutional, commercial and other purposes, to define the link between green spaces with respect to those functional spaces. For example, a green space at a school could have the useful function of becoming a play area and used by children for other active recreation. Further, green spaces near residential areas could have a variety of uses for young and old alike. An assessment of such details helped in understanding the opportunities associated with each sub-catchment land use. A detailed analysis of green spaces and potential user groups is undertaken in Stage 3. Examples of land use plans associated with the first case study site are shown in Appendix B1.

Analyses of existing drainage patterns were useful to identify SUDS locations. Investigating the drainage routes and the availability of green spaces along them determine the selection of options in Stage 4 after analysis of green spaces. For example, if there is no green space between the start of a branch sewer to the point it joins the trunk sewer, then the sub-catchment will not have sufficient attenuation potential and peak flows will be transferred downstream. Examples of drainage networks plans associated with the first case study site are shown in Appendix B1.

Stage 2

Hydraulic evaluation of the catchment was undertaken to understand the causes of flooding in the catchment. Flooding could occur due to several reasons including location of developments in floodplains, lack of capacity in the drainage system and overland flows to low lying areas. The types of development identified in stage 1 were useful to assess the vulnerability of various types of developments to flooding. The locations of green spaces adjacent to watercourses were useful in mitigating flooding at some sites.

Stage 3

The distribution of various land uses was useful for assessing the locations of open spaces in the various sub-catchments as well as their links to other land uses. This helped in examining the potential for SUDS. According to DEFRA (2005), 5 to 7 percent of space was required for planning of attenuation and treatment volume for SUDS. Additional space was required for developing conveyance systems if space is available, otherwise underground pipes will be needed for conveyance. Dry areas in SUDS (e.g. dry detention basins) could be useful for active recreation, the wet spaces (ponds and wet basins) may not be useful for active recreation and more space will be required for accessing such areas.

The spatial distribution of the green spaces with respect to the watercourse was also needed to understand the potential for integrating green spaces with SUDS. Green spaces located in proximity to the watercourse but beyond the floodplain have higher potential for storm water management while this decreases in the higher areas of a sub-catchment. Hydraulic evaluation of the catchment in stage 2 was useful in selecting green spaces which was not be affected by flooding.

Stage 4

The development of SUDS options was carried out using the previous three stages.

1. Link to stage 1- The drainage pattern was needed to identify the lower reaches of the catchment where attenuation controls could be considered. The land use pattern (spatial and areal distribution) in stage 1 provided indications of areas where such use could be possible.
2. Link to Stage 2- The hydraulic evaluation provided flooding locations and thus showed the flow contributions from various areas which indicated which developed areas should be attenuated.
3. Link to stage 3- was useful to define the type of recreational interactions possible by using various types of SUDS.

Various types of SUDS, such as dry and wet basins and ponds were considered in the options so that a well informed final decision may be taken regarding the preferred solution for a subject catchment. As the soil type in the case study areas were impermeable, infiltration methods were not considered. Further, due to the presence of back to back housing in most residential estates, swales were not deemed feasible in most housing estates. Public or institutional areas were more appropriate for planning of SUDS as there weren't logistical difficulties of land acquisition.

SUDS parameters were calculated using the methods recommended in DEFRA (2005) and is shown in Box 4-1 which included outline methods of calculating SUDS attenuation, treatment and long term storage volumes. The detailed definition of parameters and the theoretical justification of the methods are presented DEFRA (2005).

Each SUDS option was then assessed for the various indicator attributes as described in section 4.2. For example, if a dry detention basin was an option, then its attributes would be

- Water visibility: no permanent presence of water (low water visibility)
- Aesthetics: Dry grass area (corresponds to limited amenity value)

The indicators are scored in Stage 6 based on the type of attribute associated with each indicator.

Box 4-1: Calculations for SUDS parameters

The size of SUDS is determined using the following steps of calculations:

1. Green field runoff for a particular return period.

$$(1.08\ (A/\ 100)^{0.89} SAAR^{1.17}.\ SPR^{2.17})\ l/s \qquad \text{....Eq. 4.3}$$

Where, A is the development area excluding large open spaces
SAAR is the Standard Average Annual Rainfall assessed over a period of years
SPR Standard Percentage Runoff

2. Using green field runoff and Basic storage volume and adjusted storage volumes calculate final attenuation storage volumes.

Basic storage volume, $BSV = U.\ \alpha\ A\ \ m^3$ ....Eq. 4.4

Where,
U is the attenuation storage volume per unit area
α is the proportion of impervious area requiring storage
A is the development area excluding large open spaces

Adjusted storage volume, $ASV = SVR \times BSV\ m^3$ ....Eq. 4.5

Where,
SVR is the Storage volume ratio
BSV is the Basic Storage Volume

Final Attenuation volume= $HR \times ASV\ m^3$ ....Eq. 4.6

Where,
HR Hydrological region volume storage ratio
ASV is the Adjusted storage volume

3. Treatment volumes

$TV= 9A.M_560\cdot(SPR/2 + (1 - SPR/2).\ \beta\ PIMP/100)\ m^3$ ....Eq. 4.7

Where,
A is the development area excluding large open spaces
M_560
SPR is the percentage runoff
β is the proportion of impervious area requiring storage
PIMP is percentage impermeable area

4. Long term storage volumes for subcatchments using land use and rainfall characteristics

$LTV= (RD \cdot LTF \cdot AP)\ m^3$ ....Eq. 4.8

Where,
RD is the Rainfall depth for 100 hr 6 hr event
LTF is the long term storage factor
AP Impermeable area (A.PIMP/100)

Source: DEFRA (2005)

Stage 5

Model scenarios were developed to represent the various SUDS options developed in stage 4. The scenarios were developed by introducing attenuation and long term storage into the drainage network at the locations identified in Stage 4. Limiting discharge for SUDS options were calculated using Equation 4-3 while a value of 2l/s/ ha was used for the outflow from long term volume as recommended by DEFRA (2005). The discharges from SUDS and long term volume thus calculated were used in the various model scenarios to represent various SUDS options.

The options were then tested for simulated rainfall to assess the attenuation generated. The resulting flow hydrograph after running the simulation were used to show the effects of various SUDS options proposed in stage 4. The results were then used to justify the storm water scores associated with various options in stage 6.

This stage also indicated whether sufficient attenuation was generated to control the flooding. If the options were not producing sufficient reductions then options could be changed or more schemes in other sub-catchments would need to be introduced.

Stage 6

Each of the attributes was scored for each option in the range of 1-3. This was called the attribute points. Each attribute points were multiplied by the normalised weightings associated with each indicator to give the indicator score. Each of the indicator scores was added to determine the SUDS option score. The various SUDS option scores were compared to determine the preferred option.

Illustration of basic principles

The basic principles of the methodology developed are illustrated in the following example. Consider a conceptual urban catchment XYZ which is affected by flooding. Select two sub-catchments within the catchment to illustrate basic principles:

1. Green space area assessment

This example presents the importance of assessing green space distribution for planning of SUDS. The green spaces in the catchment are present as shown in Figure 4-1. The developed area and green spaces were analysed for the two sub-catchments and are shown in Table 4-4. From Figure 4-1, it is evident that although green spaces are present in both the sub-catchments, there is more potential for planning of SUDS in sub-catchment A as green spaces lie in low lying areas. However, SUDS are not feasible in sub-catchment B as the green spaces lie in the upper part of the residential areas. The direction of the local storm water drainage in both the sub-catchments is indicated by arrows. The residential areas in B would drain towards the watercourse and the green spaces cannot be used for attenuation.

Table 4- 7: Quantitative presence of green spaces

Subcatchment	Developed Area	Green space	SUDS possibility/ constraint
(1)	(2)	(3)	(4)
A	16	5	Potential for SUDS
B	19	1	No potential for SUDS

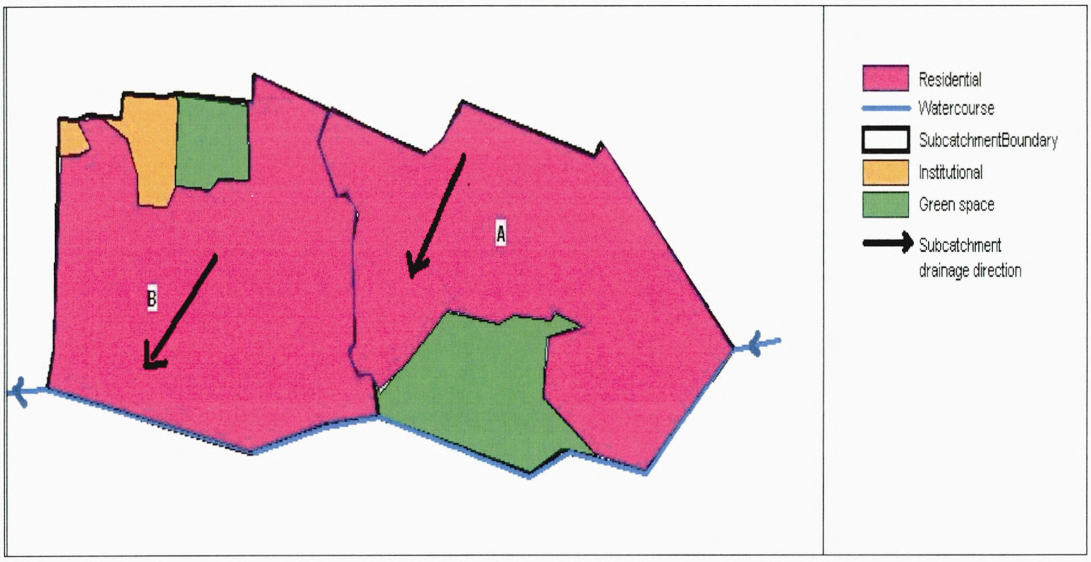


Figure 4- 1: Comparison of green space locations in the two subcatchments

2. Calculation of SUDS sizes

The procedure for calculations of SUDS volumes has been explained in the methodology section (Box 4-1). In order to illustrate the calculations for two subcatchments in the theoretical catchment two example SUDS schemes were conceived as shown in Figure 4-2 for subcatchment A.

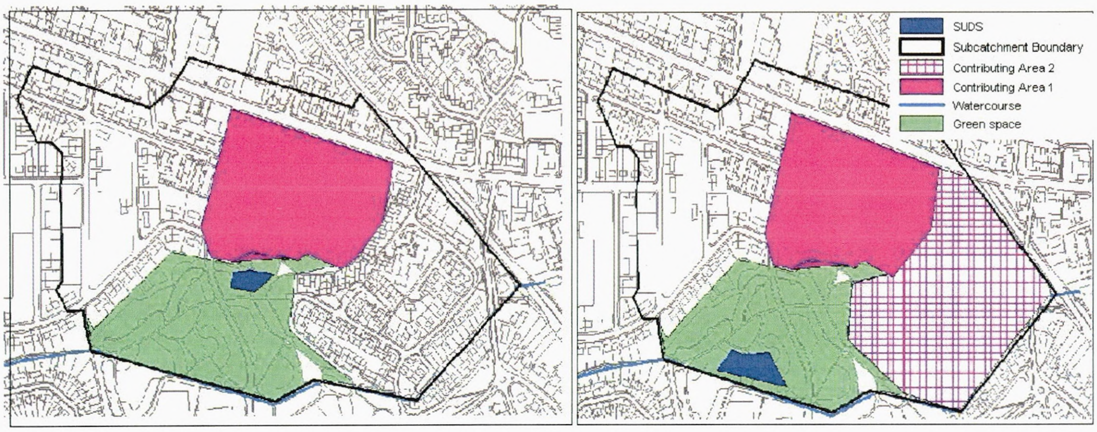


Figure 4- 2: The above figure shows two SUDS options (Option 1 in the left and Option 2 on right)

The attenuation volume and treatment volumes were calculated using the process described in DEFRA (2005). The regional and local input data as determined using DEFRA (2005) are presented in Appendix A2

Greenfield runoff was calculated using equation 4.3 and is shown in Table 4-8

Table 4- 8: Greenfield Runoff

Parameters		Value
Area (ha)	A	11.00
Annual Rainfall (mm)	SAAR	1000.00
Soil Runoff Coefficient	SPR	0.47
Catchment annual peak flow	QBAR	80.61
Mean annual peak flow per unit area	QBAR/A	7.33
1 yr peak discharge per unit rate of runoff (l/s)	Q1yr	68.52
30 yr peak discharge per unit rate of runoff (l/s)	Q30yr	153.16
100 yr peak discharge per unit rate of runoff (l/s)	Q100yr	209.58
200 yr peak discharge per unit rate of runoff (l/s)	Q200yr	241.83
1 yr peak discharge per unit rate of runoff per unit area (l/s/ha)	Q1yr/A	6.23
30 yr peak discharge per unit rate of runoff per unit area (l/s/ha)	Q30yr/A (l/s)	13.92
100 yr peak discharge per unit rate of runoff per unit area (l/s/ha)	Q100yr/A (l/s)	19.05
200 yr peak discharge per unit rate of runoff per unit area (l/s/ha)	Q200yr/A (l/s)	21.98

Using graphs of green field runoff per unit area (Qbar/A) and PIMP from DEFRA (2005) manual, U (attenuation storage per unit area) was interpolated and the values presented in Table 4-9. Then basic storage volume and adjusted storage volumes and final attenuation volumes were calculated using the following equations 4.4, 4.5 and

4.6 The values of storage volume ration (SVR) and hydrological region volume ration (HR) were determined using DEFRA (2005) as shown in Appendix A2.

Table 4- 9: Attenuation volumes

Parameters		Value
Attenuation storage volume per unit area (m^3/ha)	U1yr	56
	U10yr	100
	U30yr	136
	U200yr	174
Basic storage volumes (m^3)	BSV1yr	616
	BSV10yr	1100
	BSV30yr	1496
	BSV200yr	2167
Adjusted storage volumes (m^3)	ASV1yr	616
	ASV10yr	1100
	ASV30yr	1496
	ASV200yr	2167
Final estimated attenuation storage Volumes (m^3)	At.Vol.1yr	616
	At.Vol.10yr	1155
	At.Vol.100yr	2067.12
	At.Vol.200yr	2383.7

Then treatment volume was calculated using equation 4.7. Various parameters used in the calculations of the treatment volume are shown in Table 4-10

Table 4- 10: Treatment volumes

Parameters		Value
Development area (ha)	A	11
PIMP %	PIMP	0.6
Impervious area requiring storage %	BETA	0.75
Soil runoff coefficient	SPR	0.45
5 year/60 min rainfall depth (mm)	M_560	17
Treatment volume (m^3)	TV	1161.27

Relevant parameters for sizing SUDS using the above calculations are summarised in Table 4-11

Table 4- 11: SUDS design parameters

Parameters	Value
Developed areas (ha)	11
AV 30 (m^3)	1600.72
AV 10 (m^3)	1155
TV (m^3)	1161.27
LTV (m^3)	1089

Two SUDS options were proposed: 1) Basin and 2) Pond. The basin was proposed to attenuate 35% of the developed area of the sub-catchment while the pond was proposed to disconnect 84% of the developed area. It was also proposed that 15% of the developed area would contribute towards long term volume for option 2. This information is summarized in Table 4-12.

Table 4- 12: Proposed proportion of developments contributing to Attenuation and Long term volumes

	Proportion of developed area contributing to Attenuation and Treatment volume (PA1)	Proportion of developed area contributing to Long Term Volume (PA2)
Option 1, Basin	0.35	0
Option 2, Pond	0.84	0.15

Using the contributions proposed in Table 4-12, SUDS parameters were calculated as shown in Table 4-13.

Table 4- 13: Calculations for individual SUDS Options in A

Option	1	2	Remarks
	Basin	Pond	
Contributing areas	A1	A1+A2	
Attenuation volume, AV (m^3)	404	1345	Pond AV=PA1(Table 4-12)*AV 30 (Table 4-11) Basin AV=PA1 (Table 4-12) *AV 10(Table 4-11)
Treatment volume , TV(m^3)	412	915	TV= PA1(Table 4-12)*TV(Table 4-11)
SUDS volume (m^3)	816	2260	Pond Volume =AV+2TV Basin Volume =AV+TV
Long term volume, LTV (m^3)		163	LTV (Table 4-12)*PA2 (Table 4-13)

Note:

Once the volumes were determined they were used as storage input for the hydraulic model. Input of these parameters is needed to confirm the benefits of reduction of peak flows in the catchment. This is further illustrated through the detailed case study examples in chapter 5 (section 5.6) and Chapter 6 (section 6.6) respectively.

3. Scoring of options

This section explains the scoring of the two SUDS options shown in Figure 4-2. Table 4-14 explains the scoring for Option 1 while Table 4-15 explains the scoring for

Option 2. Each of the indicators is scored based on the attributes (Column 3) in the range of 1-3. The attributes have been defined in section 4.2. Based on the type of SUDS selected, and site attributes identified from GIS plan, corresponding scores according to the definitions in section 4-2 are allotted to each indicator. The scores are called attribute points and are shown in Table 4-14 and Table 4-15, column 2.

Table 4- 14: Initial indicator scores of Option 1 (Dry basin shown in Figure 4-2 left side)

Indicators	Attribute Points	Indicator Attributes
(1)	(2)	(3)
Access	3	Site is accessible by footpath and a road (Site characteristic, Figure 4-2)
Water visibility	1	No Permanent pool of water (proposed SUDS characteristic)
Aesthetics	1	Dry basin with only grass vegetation (proposed SUDS characteristic)
passive security	2	Proposed SUDS have development on two sides (Site characteristic, Figure 4-2)
Multi-purpose	3	The site is next to a play area and houses and provides an opportunity for multi-purpose recreation. The basin itself can be moulded into play space (Site and device characteristic, Figure 4-2)
Safety	3	Proposed depth greater than 1m (proposed SUDS characteristic)
Ownership	3	Public (Site characteristic, Figure 4-2)
Flood return period	2	flood management up to 10 yrs (proposed SUDS characteristic)
Attenuation volume	1	Less than one-thirds area connected to SUDS attenuation volume (Table 4-13, Column 2)
Long term storage	1	Less than one-thirds area connected to long term storage (Table 4-13, column 3)

Each attribute point should be multiplied by the normalised weightings associated with each indicator (developed in section 4-5) to give the final indicator score. So, the attribute point in column 3 and column 4 of Table 4-16 will be multiplied by the normalised weightings of Column 2, (refer to Table 4-16) to produce the corresponding scores for each option in Table 4-17 (shown in column 2 and 3 of Table 4-17).

Table 4- 15: Initial indicator scores of Option 2 (Pond shown in Figure 4-2 right side)

Indicators	Attribute Points	Indicator Attributes
(1)	(2)	(3)
Access	3	Site is accessible by footpath and a road (Site characteristic, Figure 4-2)
Water visibility	3	No Permanent pool of water (proposed SUDS characteristic)
Aesthetics	3	Dry basin with only grass vegetation (proposed SUDS characteristic)
passive security	1	Proposed SUDS have development on two sides (Site characteristic, Figure 4-2)
Multi-purpose	3	The site is next to a play area and houses and provides an opportunity for multi-purpose recreation. The pond will also be useful as a multifunctional space. (Site and device characteristic, Figure 4-2)
Safety	1	Proposed depth greater than 1m (proposed SUDS characteristic)
Ownership	3	Public (Site characteristic, Figure 4-2)
Flood return period	3	flood management up to 30 yrs (proposed SUDS characteristic)
Attenuation volume	2	More than one-thirds but less than two thirds area connected to SUDS attenuation volume (Table 4-4, Column 4)
Long term storage	2	More than one-thirds but less than two thirds area connected to long term storage (Table 4-5, column 6)

Table 4-16: Normalised weightings to be assigned to each initial scores

	Normalised Weightings	Option 1 attribute points	Option 2 attribute points
(1)	(2)	(3)	(4)
Access	0.6	3	3
Water visibility	0.7	1	3
Aesthetics	0.7	1	3
passive security	0.6	3	3
Multi-purpose	0.8	3	3
Safety	0.8	3	1
Ownership	0.7	3	3
Flood return period	1.7	2	3
Attenuation volume	1.6	2	2
Long term storage	1.6	2	1

Each of the normalised indicator scores will be added to determine the total score associated to each option. So, adding all the scores in column 2 of Table 4-17 will help determine the total score for option 1 (shown in column 2, last row).

Table 4-17: Normalised scores added to obtain total scores

	Option 1 Normalised Scores	Option 2 Normalised scores
(1)	(2)	(3)
Access	1.8	1.8
Water visibility	0.7	2.0
Aesthetics	0.7	2.2
passive security	1.9	1.9
Multi-purpose	2.3	2.3
Safety	2.4	0.8
Ownership	2.0	2.0
Flood return period	3.4	5.1
Attenuation volume	3.2	3.2
Long term storage	3.2	1.6
Total score	**21.6**	**22.9**

Total score for Option 1

Total score for Option 2

The option having the highest total score is selected as the preferred option. In this example, option 2 is the preferred option as it received a higher score.

Critical appraisal of methodology

The conceptual framework (shown in Figure 3-1) includes aspects of urban planning, storm water planning and green space planning as discussed in Chapter 3. Trans-disciplinary research has become a requirement for spatial planning as the planning and management of the countryside has been characterised more by tension than cohesion during the past 50 years due to the sharp demarcation of sectoral interests (Fry 2001). An integrated approach of landscape planning has been supported by various researchers including: Nassauer (1995); Décamps (2001); Naveh (1998); Antrop (1998) and Naveh (2001). The methodology involving developed areas, open space and water, thus fits into an integrated approach to landscape planning.

The approaches of storm water planning and recreation planning are quite different. The planning of storm water management is highly deterministic while that of amenity is highly perceptual. An engineer designs the drainage systems to completely follow the desired hydraulics based on technical guidance. This is shown by the work of several authors such as Yen and Tung (1993). In this approach there is lack of appreciation of the fact that designed surfaces are also public spaces as well as ecological spaces. In contrast, professionals such as architects and planners who design and plan recreational spaces focus on public perception and ecological aspects (Frumklin *et al.* 2004). This research is aimed at finding the middle ground between the two. The approach is therefore neither completely deterministic nor completely perceptual. It must be a compromise between the two approaches.

Recreational indicators represent perceptual or subjective aspects in this research, which is evident from the work of Marcus and Francis (1998). This makes it difficult to measure compared with the measurement of storm water indicators which have more clearly defined boundaries. It means that the boundaries had to be based on previous indicative perception studies or based on intuitive reasoning of what might be acceptable hypothesis based on existing knowledge. For example, the accessibility of green space was found to be a factor in recreation for green spaces (Handley *et al.* 2003) and should be used for SUDS amenity evaluation as SUDS are also landscape features. Hence, this was selected as a recreational indicator.

This research provides an approach which is based on elements of both objectivity and subjectivity. Although the approach has been to reduce the elements of subjectivity as much as possible, some elements of subjectivity were inevitable considering the nature of the research area. The tradeoffs have been made with extreme caution, after consulting various experts, and a wide review of the literature. For example, the weightings were assigned after a perception survey using a focus group comprising planners, engineers and academicians as discussed in section 4.5. Each potential indicator and their likely boundaries were selected after inferences were made from the works of previous research as shown in Table 4-1 and Table 4-2.

4.7 ASSUMPTIONS IN THE METHODOLOGY

- It was assumed that the perception of the planners would be representative of the majority of people, although people may have a range of views, depending on their age, gender and requirements. This was based on the premise that planners generally know the requirements of their constituents.
- The storage added in the impermeable area module reflects the attenuation produced by SUDS. But, the performance of SUDS will also depend on other factors, such as inlet and outlet conditions. However, this is based on DEFRA's (2005) approach, which provides coarse estimates of attenuation in the catchment.
- It was assumed that integration of SUDS with open spaces would add value to the landscape. However, poor design has been shown to decrease the appeal of landscapes (Emmerling-Di-Novo 2007).

4.8 LIMITATIONS

The limitations of the research were as follows:

- HYDRAULIC MODELING SOFTWARE. Software is essential for the modelling of one-dimensional flow. However, flooding is a three-dimensional phenomenon. Overland flows could affect the locations of flooding, depending on available escape routes; but modelling this is difficult in existing software. A hydraulic model represents only an approximation of existing circumstances of flooding (Chow, Maidment, and Mays 2005).
- LAND USE CHANGES. Although, existing development proposals were included in the studies, unforeseen future developments could affect the sewer flows.
- OTHER INTEGRATION FACTORS. This research considered only some of the integration factors applicable to integrated planning. However, several other factors, such as quality of water, biodiversity, and other aspects of environmental improvement, have not been considered due to lack of time and resources.
- THIRD PARTY ISSUES: Basic hydraulic models developed by consultants employed by the local authorities for the development of drainage plans were

used for this research. Although, there could be some errors in their work, re-verification of the models was carried out for ensure that they approximate the actual network. Also, site visits was conducted to see the ground conditions associated to models. Similarly, to confirm the accuracy of the GIS data provided by the local authority, site visits were undertaken.

- SAMPLE SIZE. As the method of research was case study which required detailed investigation of several parameters in the natural settings of a catchment, so the size of samples was limited to two. The first case study was intended to assess the applicability of the framework in one area while the second one was intended to test its applicability in a totally different area so that the wider applicability of the framework is understood. Also, time constraints were another factor to limit the studies to two catchments.
- CONVENTIONAL DRAINAGE. The conventional drainage options were not considered as part of this research. A comparison with the conventional solutions would have highlighted the advantages and disadvantages of the proposed sustainable options. This, however, was done by Hyder consultants who had developed conceptual solutions. Their results indicated that either the conventional solutions caused downstream flooding or their cost was excessive (Aukerman *et al.* 2008).
- COSTING. The costing was not carried out to determine the economic feasibility of the various options due to time constraints. The costing models for SUDS are available and can be used to compare SUDS and conventional options.
- PUBLIC OPINION SURVEYS. The public opinion surveys represent important methods for qualitative assessment but need detailed perception analysis of various age groups and their habits. However, they were not carried out as focus group survey discussed in section 4-5 was deemed sufficient for the purpose of this research. There was also a constraint of time and resources for undertaking such work.

4.9 ETHICAL ISSUES

As the methods of data collection and analysis have become more sophisticated and penetrating, awareness and concern over the ethics of research have increased (Whitebeck 1998). Gregory (2003) suggests that research should involve consent from people likely to be affected by the research. However, no set criteria are applicable to all research, and one should assess the risks and benefits for humanity as well as for the researcher (Bernard 2000).

There were some ethical issues involved with the various types of data collection and analysis associated with this research. The use of flooding data was sensitive information that needed to remain confidential. Interviewing of local authority officials was done with their consent. The project was being undertaken, not only for the development of knowledge, but also to inform better planning and decision-making by the local authorities of the case study catchments.

4.10 TESTING OF THE CONCEPTUAL FRAMEWORK

The conceptual framework outlined in Chapter 3 and the methodology outlined in this chapter has been tested in using two case studies discussed in chapters 5 and 6 respectively. The two case study areas have different land use plans and thus provide opportunity to test wider potential applicability of the methodology. They show the application of the six stages of framework and summary of the results and analysis. The calculations and supporting data associated with the two case studies are presented in Appendices B and C.

<u>*Selection criteria for the case study locations*</u>
The two case study catchments were selected based on the following criteria:

- Flooding
- Availability of model data -
- Presence of green spaces

Existence of flooding was the first criteria as the investigations were carried out to reduce the flooding using integrated schemes. The second criterion was the availability of integrated hydraulic model with both sewer and watercourse data. As the main focus of the study was the develop and test a novel framework, existence of model data was perceived as an important criteria which would save time and avoid duplication of work carried out by private consultants. The third criteria: presence of green spaces was necessary for development of SUDS.

Description of the case study locations

Light Burn catchment in the East End of Glasgow was selected as the first case study while Spateston Burn catchment in Renfrewshire was selected as the second case study area. The locations of the two catchments are presented in sections 5.1 and 6.1 respectively. The use of case studies was intended to answer various research questions (presented in section 1.1). Both case studies had residential areas with a mix of open spaces, housing, schools transportation network and drainage networks. Investigating opportunities for integration of water management with open spaces in these settings provided understanding of conflicting interests. After initial investigations, three subcatchments were selected in each case study area for detailed application of various aspects of the framework, although the process was carried out within the overall context of the catchment. For example, detailed green space assessment and potential for storm water management was discussed for three sub catchments; however the overall green space network in the catchments was also determined so that wider spatial planning benefits could also be analysed.

Three subcatchments were selected in each catchment so that they represented various proportions and distributions of open spaces and other land uses. A greater number of subcatchments could have provided more understanding of the various issues involved; however there was also a need to balance the amount of output so that a thorough analysis and appraisal could be conducted. The selection of subcatchments was done so they were representative of development patterns and open space patterns generally occurring in urban areas. For example, in the first case study in Chapter 5, Garthamloch represents a partially developed subcatchment with large amounts of informal green spaces. The second subcatchment, Skerryvore is well developed with established green spaces such as parks, playgrounds, and other amenity spaces. However, the third subcatchment, Cardowan represented an overdeveloped area with hardly any green spaces.

Data collection methods

The application of the methodology was depended on reliable data. Data was collected from several sources. Sewer network data was mostly obtained from Scottish Water and watercourse network data was provided from the local authority. For sections where the information was incomplete and insufficient, site surveys have been carried out by the consultants (MWH, Hyder and JBA) and updated information was obtained. Information about the land use plans was collected from local authorities which were Glasgow City Council and Renfrewshire Council in this case. Site visits were also undertaken to confirm the accuracy of the data collected.

Description of hydraulic models used for the case study locations

Storm water attenuation benefits were tested using hydraulic models. Light burn catchment hydraulic model developed by Hyder and Montgomery Water Harza (MWH) consultants was used while a model developed by JBA consultants was used for Spateston catchment. Both the models were developed using Infoworks CS software and represented both the sewer and the watercourse network. Site visits were also undertaken to further confirm the validity of the sewer and watercourse data used in the model. The soil type used for both the models was type 4 as was indicated by the FEH data. After obtaining the models, they were verified again using actual flow and rainfall data provided by these consultants. As both the models showed close co-relation between actual flows and predicted flows, they were deemed fit for the purpose of this research.

The results of the application of the methodology have been discussed at the end of each chapter i.e. sections 5.8 and 6.8 in chapters 5 and 6 respectively. Additionally, in sections 5.8 and 6.8, a discussion on various issues related to applicability of the framework for the sub-catchments and the potential of integration associated with various distributions of open spaces. An overall evaluation of the case studies in the context of existing knowledge is presented in chapter 7.

5 APPLICATION OF THE PROPOSED FRAMEWORK FOR INTEGRATED GREEN SPACE AND WATER PLANNING IN LIGHT BURN CATCHMENT

5.1 INTRODUCTION

The Light Burn catchment in Glasgow was selected to test the potential of integrated green space and water planning framework introduced in chapter 3. The catchment lies in the East End of Glasgow (refer to Figure 5-1). The area is also under a regeneration initiative of Glasgow City Council to improve its blighted image. Glasgow City Council took a keen interest in this case study and provided all relevant data required for this research.

The application of the methodology required detailed analysis to test various options. Thus, this chapter provides an overview of the issues for the whole catchment but detailed analysis for a sample of three subcatchments as discussed in section 5.2. The sample subcatchments (shown in Figure 5-2) were:

1. Garthamloch
2. Skerryvore
3. Cardowan

These subcatchments were selected to test the framework and tool developed in the research methodology. The considerations for selecting the sample of three subcatchments have been discussed in section 4.10, chapter 4.

Application of the framework is described in sections 5.2 to 5.7. Stage 1 presented in section 5.2 describes the land use and drainage patterns of the Light Burn catchment. Section 5.3 relates to the hydraulic evaluation and flood risk assessment. Green space assessment associated with stage 3 of the conceptual framework is described in section 5.4. Implementation of stage 4 of the framework is reported in section 5.5 of this chapter. Results for evaluation of SUDS related to flood management are presented in section 5.6 and are linked to stage 6. Integrated evaluation of green space planning with SUDS, associated with stage 6 of the framework, is taken up in section 5.7. Section 5.8 evaluates the results discussed in sections 1 to section 6. The supporting data are presented in Appendices B1 to B6.

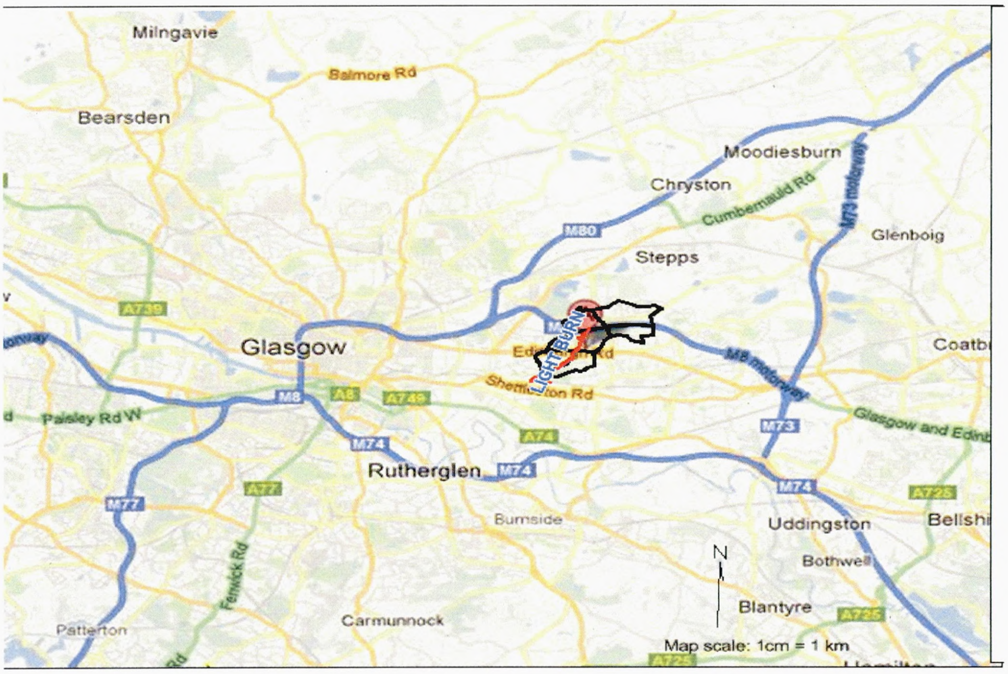


Figure 5- 1: Location of Light Burn catchment

(Source: Google maps)

5.2 STAGE 1: CATCHMENT LAND USE AND DRAINAGE ASSESSMENT

This stage deals with land use and drainage assessment for the Light Burn catchment. Step 1a shows demarcation of the boundaries of sub-catchments within the catchment. Overall drainage characteristics of the catchment are reported in step 1b, while step 1c identifies land use characteristics of the whole catchment. Step 1d and step 1e deal with sample study areas within the catchment. These sub-catchments were selected based on the criteria outlined in section 4.10. Step 1d reports the drainage systems present in the selected sub-catchments while step 1e gives a detailed account of the land use pattern in the sample sub-catchments.

Step 1a Demarcate catchment and sub-catchment boundaries

In step 1a, the catchment and sub-catchment boundaries were identified for the Light Burn catchment. The Light Burn drains into Camlachie burn to the South as shown in Figure 5-2. The delineation of the catchment and subcatchments was based on topographic data and drainage network data. The total area of the catchment was found to be 345.7 Ha. The catchment was divided into seven sub-catchments as shown in Figure 5-2. The demarcation of the subcatchments was done by taking into consideration the drainage layout in various parts of the catchments as well as developments such as housing estates, schools, commercial and industrial areas. Both watercourse as well as sewer systems were considered for the delineation of subcatchments.

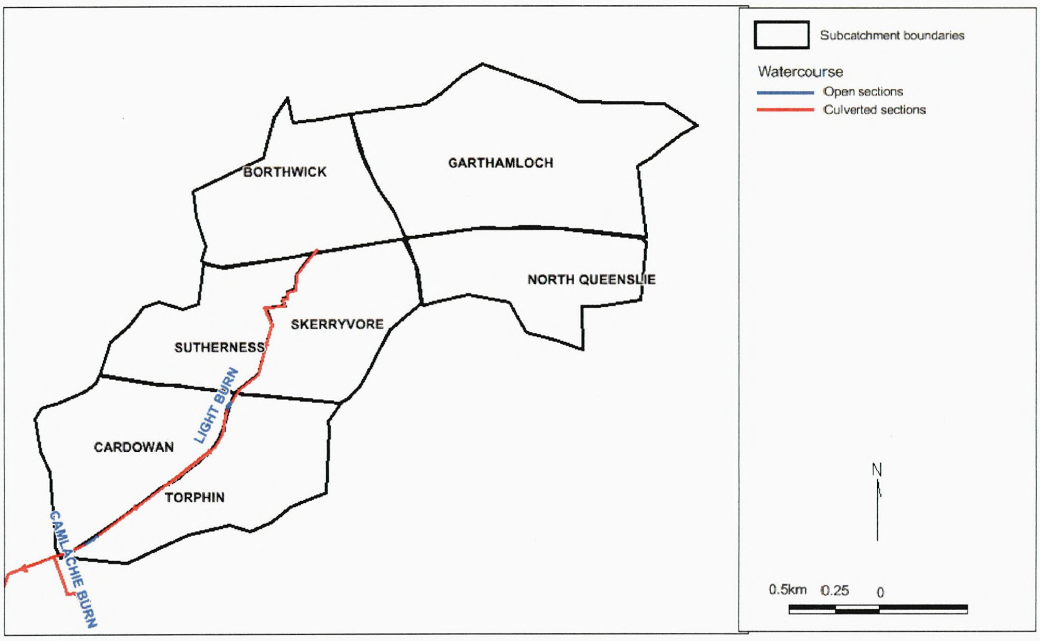


Figure 5- 2: Division of Light Burn catchment into seven sub-catchments
(Map source: Glasgow City Council)

Step 1b Study catchment characteristics

For implementing Step 1b, the drainage characteristics of the catchment were determined. It has two types of drainage systems: combined and separate. Most areas are served by combined sewers, but there are also separate sewers draining some developments as well as the motorway. The separate sewers and the motorway runoff drain into Light Burn, which passes through the centre of the catchment. The watercourse is almost completely culverted and has a low amenity value. The locations affected by flooding (obtained from Glasgow City Council), as shown in Figure 5-3, are situated towards the south of the catchment and possibly represent lack of capacity in the drainage system.

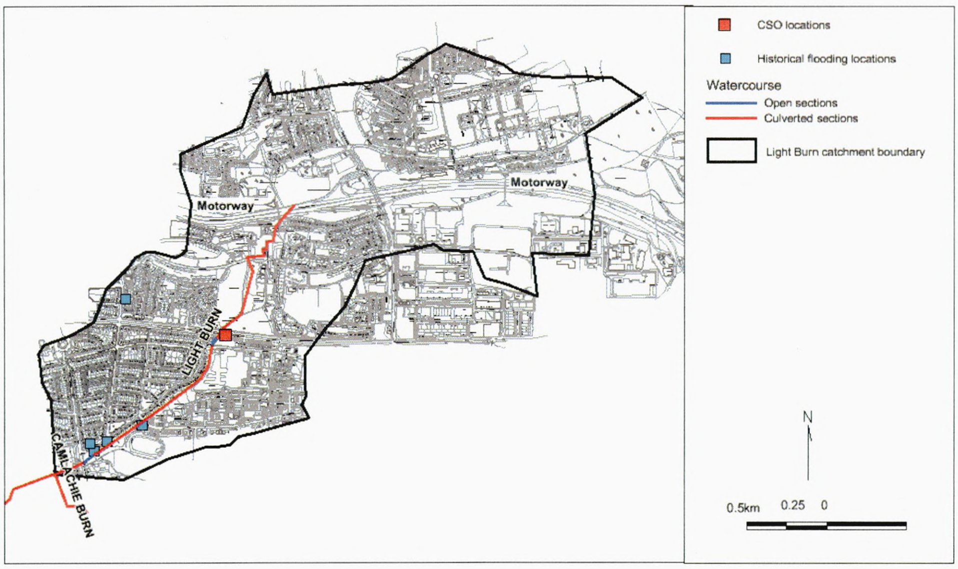


Figure 5- 3: Flood and CSO locations in the Light Burn catchment

(Map source: Glasgow City Council)

Step 1c: Study land use characteristics

Land use analysis of the catchment was carried out according to Step 1c. This catchment is mainly residential, with pockets of industrial, institutional and commercial areas. The area is also criss-crossed by transport corridors: M8 motorway in the north, running east to west, and Edinburgh Road running parallel to it. It is linked by a rail network at Carntyne Station in the south of the catchment.

The southern part of the Light Burn catchment is largely developed, while there are large green spaces in housing developments in the central and northern parts, as shown in Figure 5-4.

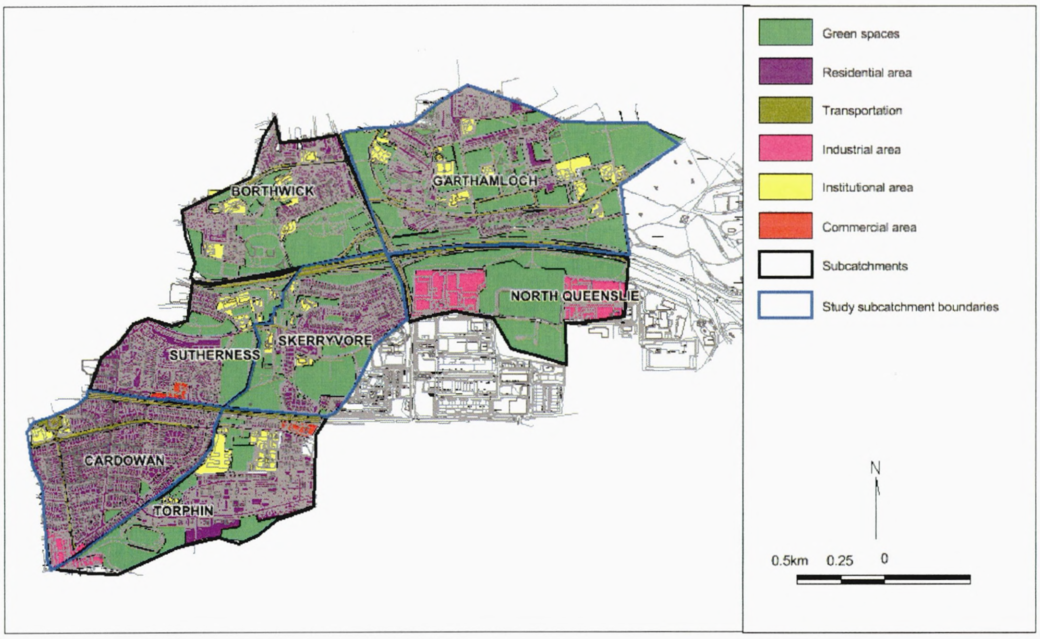


Figure 5- 4: Development pattern in the Light Burn catchment (Appendix B1)
(Map source: Glasgow City Council)

The land use within the catchment was categorised into residential, commercial, transportation, industrial, institutional and green space uses using information provided by Glasgow City Council (GCC). The distribution of land uses in the catchment is shown in Table 5-1, while distribution within each sub-catchment is shown in **Error! Reference source not found.**. Analysis of Table 5-1 and Figure 5-5 show that land use is unevenly distributed in the different sub-catchments. For example, Garthamloch and Borthwick have a very high proportion of green spaces, while Cardowan has little proportion of green spaces. Skerryvore and Sutherness also show a good proportion of green spaces (more than 20 percent) along with more than 40 percent area for housing.

Table 5- 1: Distribution of land use in the Light Burn Catchment

	Area (ha)	Percentage
Open space	113	35.7
Commercial	1	0.2
Institutional	23	7.2
Residential	131	41.4
Transport	49	15.4
	317	100

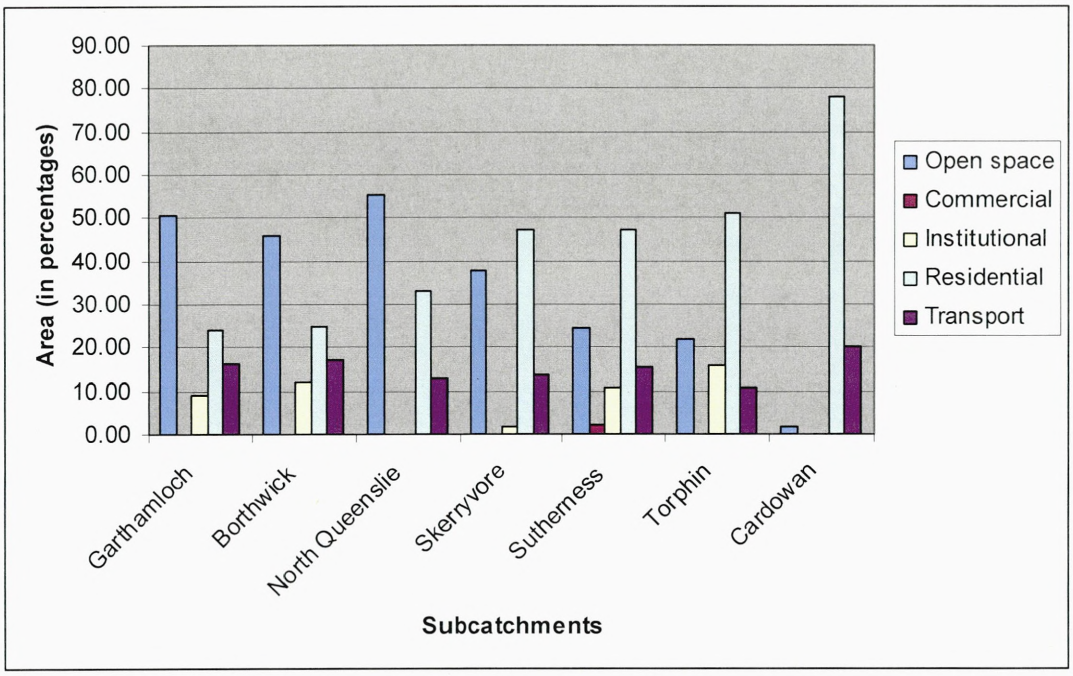


Figure 5- 5: Distribution of land uses in various sub-catchments in percentages

Step 1d: Drainage patterns in selected catchments

The drainage patterns for the three sub-catchments selected were studied. Layouts of the drainage systems in the areas are presented in Appendix B1 while the description of the drainage systems is presented as below:

Garthamloch

The site of Garthamloch has a mix of combined sewers and separate sewers. The western part of the sub-catchment (called Gartloch) has predominantly separate sewers, while the rest of the sub-catchment has combined sewers. The drainage from most of the green spaces is also likely to be discharged into combined sewers, as they form the predominant drainage pathways in the area (Appendix B1 Figure 7).

Skerryvore

The Skerryvore sub-catchment is served by combined sewers which run towards the west of the sub-catchment. Because of the limited capacity of the sewer system, frequent CSO spills have been reported immediately downstream. The Light Burn flows from north to south in the west of the sub-catchment and is culverted for most of this stretch. The depth of the culvert varies from 7 m maximum to a minimum of 1m. The drainage layout for the sub-catchment is shown in Appendix B1 Figure 12.

Cardowan

Cardowan is drained only by combined sewers, which start towards the western side of the sub-catchment and drain towards the east into the trunk sewer. The Light Burn flows parallel to the trunk sewer, draining separate sewers as well as combined sewer overflows. The Light Burn flows mainly through a culverted system, and its depth varies between a maximum of 8m to a minimum of 1m. The lower end of the system in Cardowan is historically prone to flooding due to the limited capacity of the current drainage systems. The drainage layout of the sub-catchment is shown in Appendix B1 Figure 17.

Step 1e: Study detailed land use characteristics in selected sub-catchments

Land use characteristics of the sub-catchments: Garthamloch, Skerryvore and Cardowan are described in this section. These sub-catchments are located in the upper, middle and lower regions of the catchment (Figure 5-3) to represent different topographies (Appendix B2 Figures 4, 5 and 6).

1) Garthamloch

Garthamloch is a semi developed area; with housing dominating most of the areas in the northern, southern and western parts. The southern part of the sub-catchment is low-lying, with the M8 motorway on its boundary. The current development layout is shown in Appendix B1 Figure 1; which also shows that there are vacant spaces in the central parts of this sub-catchment. A total of 168 dwelling units, comprising mainly tenement blocks along with some semi-detached housing, are located in the north of Garthamloch. There are four primary schools and one nursery school in the area.

2) Skerryvore

The sub-catchment is mainly residential with a mix of semi-detached houses and tenement blocks. There is also a large vacant area in the south of the sub-catchment. In the western part of the sub-catchment lies Cranhill Park which is a popular recreational area. There are also three schools located around Cranhill Park in the subcatchment. The land use layout of Skerryvore is shown in Appendix B1 Figure 8.

3) Cardowan

Cardowan is a densely developed sub-catchment with land use of primarily residential type. The layout of development in the sub-catchment is shown in Appendix B1 Figure 13. Land use assessment shows that residential developments comprise 72% of the space, while 24% is taken up by transportation infrastructure, i.e. roads; hence, very little space is left for recreation.

Discussion to stage 1

Stage 1 showed the method for linking development and drainage planning. Selection of sub-catchments provided areas for detailed study of integration possibilities in later stages. Analysis of distribution of development provides opportunities for linking with flooding in stage 2. The understanding of development patterns provide data for linking it to the green spaces which is considered in detail in stage 3.

5.3 STAGE 2: HYDRAULIC EVALUATION AND FLOOD RISK ASSESSMENT

Current status of flooding was determined using a hydraulic model (discussed in step 2a) for the three sub-catchments of Garthamloch, Skerryvore and Cardowan. Hydrographs of various events at the downstream ends of these sub-catchments were also analysed so that reductions in peak flows could be compared with various SUDS options in stage 5. The hydrographs are shown in Appendix B2, while the assessment of flooding is presented in this section.

Step 2a Develop integrated model

The initial model was developed by Montgomery Watson Harza (MWH) consultants in cooperation with Hyder Consultants. The model was based upon the data provided by Scottish Water, Glasgow City Council and surveys carried out by various consultants. This model integrates watercourse network with the sewer network. The model was verified with three storm events and three dry weather flow events. A soil type of category 4 was considered in the model which was determined using FEH data.

After obtaining the model from the consultants, some changes were made. Drainage networks, belonging to the Light Burn catchment and other contributing areas, were extracted from the overall model of the draining into the Dalmarnock wastewater treatment works. The overall area draining into the Dalmarnock WWTW comprises o seven catchments and Light burn is one of them. A node at the downstream end of the Light Burn catchment was selected as outfall and the network model was revalidated. Flow survey data provided by the modellers which included rainfall data, flow data and dry weather flow was used to again verify the model and was deemed fit for the purpose of this research.

Step 2b Analyse flooding from extreme events

The flooding from a 200 year event (rainfall event with a statistical probability of occurrence once in two hundred years) was assessed for the three selected sub-catchments as follows:

Garthamloch

Catchment simulations did not show any flooding in Garthamloch limited runoff were generated due to its location in the upper part of the catchment and also due to the fact that a large part of the sub-catchment in the central and southern parts were undeveloped. The current capacity in the sewer systems, therefore, efficiently handled runoff.

Skerryvore

The sewer system is surcharged in the north east part of the sub-catchment as well as in the western parts, as shown in Figure 5-6. The excess flow generated drains towards the motorway and then towards Cranhill Park, which provides natural flood escape routes. Excess runoff originating in the western parts of Skerryvore also drains towards the low lying Cranhill Park. This reduces the impact of predicted flooding in residential areas. The park lies in the lower part of the sub-catchment, and when the runoff reaches the park, it flows towards the open section of the Light Burn. Although, simulations showed potential flooding in the subcatchment, however there were no historical flooding in this subcatchment (Figure 5-3), which could be due to potential availability of flood escape routes.

Figure 5- 6: Spatial planning and flooding in Skerryvore

(Map source: Glasgow City Council)

Cardowan

Cardowan floods frequently, as confirmed by the model runs for the sub-catchment. Flooding occurs due to lack of capacity in the sewer system and culvert in some areas, as shown in Figure 5-7, and flood water would potentially move towards the lower end of the sub-catchment and cause intense flooding in those areas. Although, historical flooding sites are situated on Cardowan Road (Figure 5-3) only but the simulations show further flooding from the sewers on Carntynehall Road and Ruchazie Road. As both Carntynehall Road and Ruchazie Road have steep slopes towards Cardowan Road, the excess flow was unlikely to cause flooding at the surcharged located but would exacerbate the flooding on the Cardowan Road.

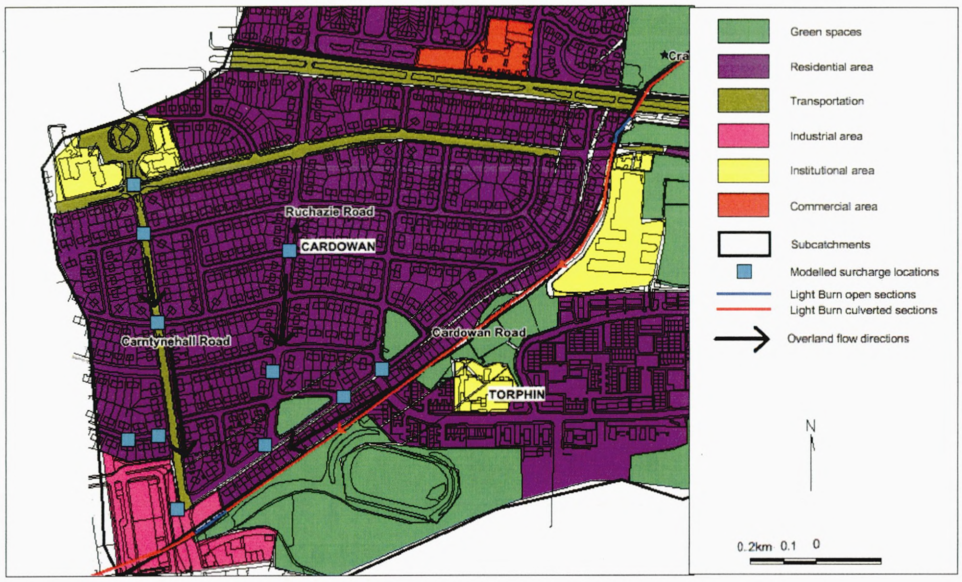


Figure 5- 7: Spatial planning and flooding in Cardowan
(Map source: Glasgow City Council)

Step 2c: Assess vulnerability of areas from sewer flooding as well as overland flow.

Modelled flooding was not observed in Garthamloch as the contributing areas are located in the headwater region. It increased in Skerryvore; but flooding is at its worst in Cardowan, towards which the whole catchment is draining. This is evident from the flooding volumes observed in these areas using the simulations: Garthamloch 42 m^3, Skerryvore 342 m^3 and Cardowan 2638 m^3.

The impact of flooding depends upon the kind of land use in the area. In Cardowan, the low lying areas are residential, while in Skerryvore and Garthamloch they are green spaces. Therefore, the vulnerability in Skerryvore and Garthamloch is limited. A comparison of flooding sensitivity in the three sub-catchments is presented in Table 5-2.

Table 5- 2: Flooding spatial sensitivity assessment in Garthamloch

Sub-catchment	Modelled Flooding using 200 yr event (m^3)	Current land use	Vulnerability	Remarks
Garthamloch	No flooding	Motorway	Essential Infrastructure	
		Green space	Water compatible	
		Residential	More Vulnerable	
Skerryvore	342	Motorway	Essential Infrastructure	
		Green space (Cranhill Park)	Water Compatible	Overland flow towards parkland are likely
		Residential	More Vulnerable	
		Institutional (schools)	Less Vulnerable	-
Cardowan	2638	Residential	More Vulnerable	Overflow at flooding location exacerbated by overland flow from other sites

The land uses in the catchment are not flood compatible (green spaces are located in areas of higher elevation while housing is situated in low lying areas). This is evident from the fact that Garthamloch, Skerryvore and Cardowan contain 40%, 31% and 2% green space, while they contain 26%, 33% and 72% of housing areas respectively.

Flooding increased in regions closer to the watercourse within each sub-catchment. This trend was clearly demonstrated in Cardowan, where most of the flooding was concentrated. Although significant sewer overflows were observed in the upper areas due to lack of capacity, the overland flows towards the low spots next to Light Burn would increase the risks there.

Discussion to stage 2

The risk of flooding is greater in the lower part of the catchment. However, the housing development density is also greater in Cardowan, which lies in the lower portion of the catchment. This causes greater vulnerability to the housing areas in Cardowan. Furthermore, there are hardly any green spaces in the Cardowan subcatchment unlike Garthamloch and Skerryvore which causes worsening of flooding. This indicates the need for more even distribution of green spaces for the mitigation of flooding.

5.4 STAGE 3: GREEN SPACE ASSESSMENT

Green spaces within the catchment were analysed and the preliminary analysis for SUDS sites was carried out in stage 3. First, in step 3a, distribution of various green space categories is identified in different parts of the catchment. Then quantitative analysis of the green spaces for Garthamloch, Skerryvore and Cardowan is described in step 3b, followed by identification of SUDS sites based on topographical analysis in step 3c. The typical green spaces in the three subcatchments (Garthamloch, Skerryvore and Cardowan) are presented in Appendix B3.

Step 3a: Categorise green spaces

Green space is distributed unevenly in the catchment. There are more green spaces in the north, adjacent to the M8 motorway, than in the south in the Cardowan area. The largest green space area within the Light Burn catchment lies in the centre and is a popular park called Cranhill Park. Other green spaces are smaller areas distributed in various parts of the catchment. Overall layout of the green spaces is shown in Figure 5-8.

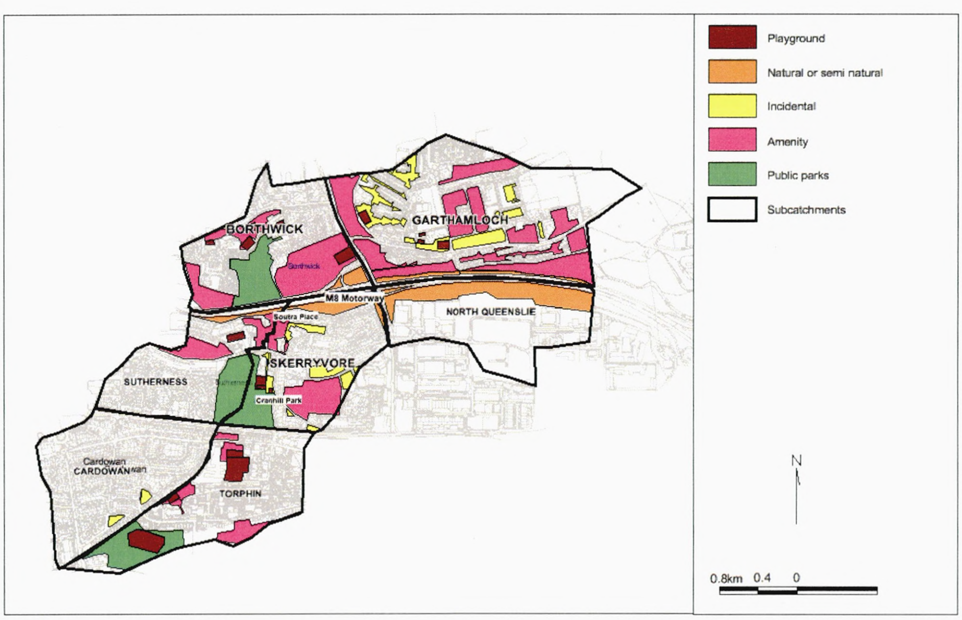


Figure 5- 8: The green space distribution in the Light Burn catchment

(Map source: Glasgow City Council)

The overall green space categories identified in the catchment are as follows:

- Parks. There are two parks developed in the catchment; one is central in the catchment (Cranhill Park), and the other in the south of the catchment. The various activities offered by the park make it popular with the local residents. The central location of Cranhill Park also adds to its popularity for pedestrians. However, there are no water features, such as fountains, ponds or open watercourses, and although a watercourse flows through it, it is culverted and hence inaccessible.
- Playgrounds. There are several local authority schools in the catchment, both primary and secondary. The schools have play areas, pitches and other grassed areas. The green spaces in the school premises have very little biodiversity. Walking surveys found that there were no water features in and around the schools.
- Natural/ semi natural. There are some natural/semi-natural green spaces on both sides of the M8 motorway consisting of trees, shrubs and other vegetation.
- Amenity green spaces. There is a large tract of grass in the north of the catchment in Garthamloch, which provides little functional value. Much of the amenity areas are not easily accessible and are distant from housing estates.
- Incidental. Small green spaces with residential and other land uses are present in all sub-catchments to varying extents.

The overall green space information is useful for analysing the connections of green spaces to potential SUDS sites within selected sub-catchments.

Step 3b: Analyse detailed green space distribution

In this section, analyses of green space distribution of the three sub-catchments, Garthamloch, Skerryvore and Cardowan, are discussed.

Garthamloch

In Garthamloch, the green space totals 40 hectares. However, nearly 14 hectares are earmarked for future developments, and the remaining 26 hectares are usable green spaces. The bulk of the green spaces, comprising 19 hectares, are in the form of amenity areas, as there are no formal parks in this sub-catchment. A significant 5.4 hectares of incidental open spaces are also present, providing door step access to green areas. The play areas are very limited, consisting of only 2% of the overall green spaces. A spatial plan of the green space is presented in Appendix B3, Figure 1 while the quantitative distribution of various green spaces is shown in Table 5-3.

Skerryvore

Skerryvore has a total green space area of 14 hectares, which includes parklands, amenity areas, incidental green spaces, playgrounds, and natural and semi-natural areas. The parkland constitutes nearly 27 per cent of the total green space, with an area of 5.1 hectares. Amenity areas are 38 per cent of the available green spaces and lie mainly in the vicinity of multi-storey residential complex at Soutra Place (refer to Appendix B3 Figure 6). Semi-natural and natural areas with woodlands are present, adjoining the M8 Motorway in the north of the catchment, and comprise 14% of the overall green spaces, with an area of 2.2 hectares. Additionally, a significant 17 % of incidental amenity areas are also present within the housing and institutional areas in Skerryvore. The distribution of various green spaces is presented in Table 5-3.

Cardowan

Only two per cent of the total catchment area is green space, accounting for 0.76 hectares out of the total area of 49 hectares. However, there are green spaces located in the adjacent sub-catchment of Torphin. The spatial plan for the green space in Cardowan is shown in Appendix B3, Figure 11.

Overall distribution of various types of green spaces in the three sub-catchments are summarised in Table 5-3.

Table 5- 3: Distribution of green spaces in sub-catchments (area in ha)

	Amenity	Playgrounds	Parks	Incidental	Natural/ Semi
Garthamloch	19.01	0.63	0	5.42	1.68
Skerryvore	5.8	0.4	5.11	2.61	2.33
Cardowan	0	0	0	0.44	0

Step 3c Evaluate green space distribution in relation to water management potential

This section presents a comparative analysis to assess the opportunities for storm water management based on the position of green spaces within the catchment. The quantitative distribution of green spaces varied across the sub-catchments. The analysis showed that less than 2% of the green space was present in the Cardowan sub-catchment, while green spaces formed nearly 20% of the areas in Skerryvore and Garthamloch. Therefore, there are ample opportunities for planning of SUDS in Garthamloch and Skerryvore, but little opportunity in Cardowan.

Skerryvore sub-catchment provides maximum opportunities for SUDS. For example the 5.1 ha Cranhill Park located beside the culverted watercourse which would be a useful site for regional SUDS such as ponds and detention basins. However, no such multifunctional parks are present in Garthamloch, although there are amenity areas where SUDS could be potentially located as shown in Table 5-4.

Within the housing estates, green space distribution affects the potential for storm water management. Greater linear green spaces within housing areas, as in Garthamloch, not only provide greater permeability (permeability refers to the extent to which urban forms permits or restricts the movement) for pedestrians but also opportunities for swales. Garthamloch provides maximum space for swales, followed by Skerryvore. There are no public green spaces for swales in Cardowan and, hence, it is difficult to consider swales in the sub-catchment (refer to Table 5-4).

Greater presence of incidental green spaces could facilitate development of detention basins in Garthamloch and Skerryvore. In Skerryvore, conveyance to the basins will need to be through storm water pipes as there are no communal spaces for swales. However, Garthamloch offers greater potential for basins as connecting swales would be developed through linear communal green spaces present in the sub-catchment. The options for SUDS development in the sample sub-catchments is discussed in the next section. A summary of opportunities for SUDS is provided in Table 5-4.

Table 5- 4: Green space distribution and opportunities for SUDS

Green space location and opportunities	Garthamloch	Skerryvore	Cardowan	Comparative evaluation
Parks	No parklands	Large parkland (5.1 Ha)	No parklands	Maximum parkland in Skerryvore
Opportunities/ Constraints	NA	Potential SUDS sites beside watercourses, multi-functional sites	Lack of green spaces for SUDS	Maximum integrated opportunities in Skerryvore
Amenity areas	Several large amenity areas	Open spaces present	No space	Most amenity areas in Garthamloch
Opportunities/ Constraints	Lower amenity detention basins and ponds (19.ha)	High amenity value detention basins and ponds (5.8 ha)	No opportunities	Most SUDS amenity areas in Garthamloch, however lower amenity value due to lack of multi-functional spaces
Housing green spaces	Linear green spaces in Gartloch Road (Refer to Appendix B3 Figure 1)	Limited linear green spaces	No linear green spaces	Garthamloch has most green spaces within housing estates
Opportunities/ Constraints	Maximum swale potential (5.42 ha)	Some opportunities for swales	No swales	The areas offer opportunities for multifunctional SUDS
Institutional grounds	Several institutional grounds	Some institutional grounds	No green spaces within housing estates	
Opportunities/ Constraints	The institutional areas provide several options for locating detention basins (0.3 ha)	Sites for basins are limited	No SUDS possible	Institutional opportunities can be useful for local attenuation but not regional as they are not located near watercourses

(Green space layout in the three sub-catchments presented in Appendix B3)

Discussion to stage 3

The amounts of green spaces were related to the potential for development of SUDS in an area. For example, there is little SUDS potential in Cardowan whilst Garthamloch and Skerryvore present ample opportunities. Larger green spaces such as parks and large amenity areas as present in Garthamloch and Skerryvore provide opportunity for regional SUDS such as ponds and detention basins.

The green space in Torphin in accessible for residents in Cardowan Road, but cannot be used for storm water attenuation of runoff from Cardowan sub-catchment as it lies outside the sub-catchment on the opposite side of the Light burn. Stage 3 application of the framework shows that although a green space can be accessible and may be suitable for recreation but may not be useful for SUDS unless present within the same sub-catchment or other hydraulically feasible locations. Previous research into green spaces planning by Giles-Corti *et al.* (2005), Fuller *et al.* (2007), Dunnett *et al.* (2002) have emphasized the importance of accessibility and recreation, but this investigation shows examples where recreation can or cannot be integrated with SUDS . Such integrated considerations have been used for planning SUDS options and are described in detail in Stage 4.

5.5 STAGE 4: PLANNING INTEGRATED SUSTAINABLE DRAINAGE OPTIONS

This section describes various SUDS options within the selected sub-catchments. Steps 4a and 4b deal with storm water and recreational aspects respectively of SUDS options. Plans for the various options as well as calculations of storage and treatment volumes of SUDS are presented in Appendix B4. Schemes were not proposed for Cardowan as GIS plans and site investigations showed lack of sufficient space for implementation of SUDS and will not be discussed further.

Step 4a Plan SUDS Options - Storm water aspects

This section deals with quantitative storm water planning aspects related to various proposed SUDS options. The plans relating to various SUDS options are also presented with each option. Site visits were also undertaken to confirm the topography, as well as accessibility, of various options.

Garthamloch

Five SUDS options are considered in the Garthamloch sub-catchments. This section discusses storm water issues associated with each option.

Option 1: One pond at Inishail Road

Two contributing areas (GCA2 and GCA3 as shown in Figure 5-9) totalling 11 hectares would drain this pond located at Inishail Road. GCA2 is served by combined sewers while GCA 3 is served by separate sewers. The separately sewered areas can be directly connected to SUDS while the combined sewered areas would need disconnection into storm sewers or swales before they could be connected to the pond. In case of development of swales or storm sewers, existing combined sewers can be used for foul flow. Visits confirmed that site conditions for the pond, including access for works and the local topography, are favourable. There was no long term volume proposed for this SUDS option. Schematic plan for the option is shown in Figure 5- 9.

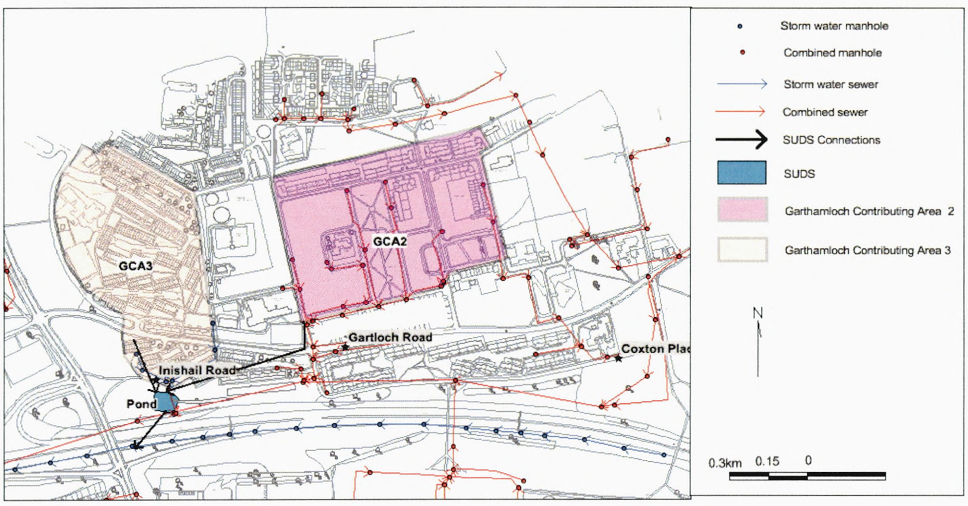


Figure 5- 9: Plan for Garthamloch SUDS option 1 (pond)

(Map source: Glasgow City Council)

Option 2: One wet basin at Inishail Road

An end of pipe wet detention basin would be served by the same contributing area as Option 1. The basin is proposed at the same site (refer to Figure 5-9) as the pond in the previous option. The site beside the basin would be used as part of this proposal for storage of long term volume. The long term storage area would be mobilised when the peak flow exceeds 10 year return period flows. This option utilises 10% of the developed area for contributing towards long term storage volume. Schematic plan for the option is shown in Figure 5-10.

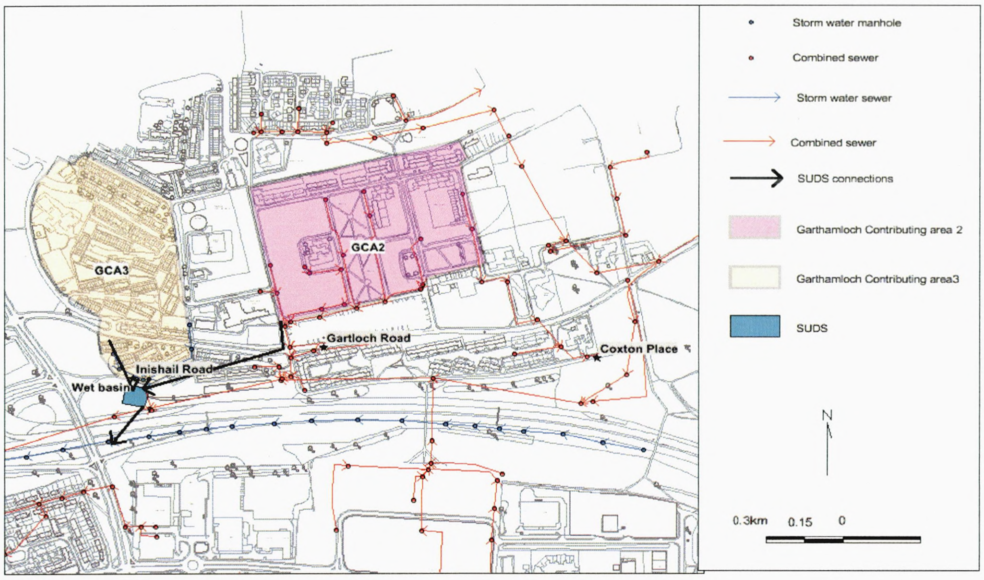


Figure 5- 10: Plan for Garthamloch SUDS option 2 (wet basin)
(Map source: Glasgow City Council)

Option 3: Two Ponds: one at Inishail Rd. and another adjacent to Gartloch Rd.

The total areas contributing to the two ponds are the same as in the previous two options. The proposed ponds would be served by the combined sewers and separate sewers of the contributing areas. The separate sewer areas could be directly drained into the pond, while the areas serving the combined sewer would need disconnection from them. Once the areas are disconnected then they could convey the runoff into swales or storm water sewers which would need to be developed in this sub-catchment. Schematic plan for this option is shown in Figure 5-11.

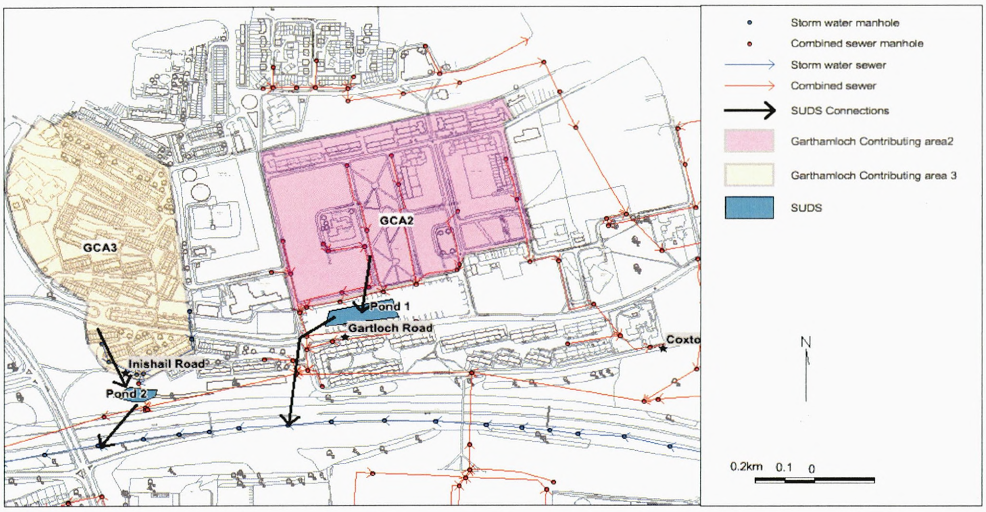


Figure 5- 11: Plan for Garthamloch SUDS option 3 (Two ponds)

(Map source: Glasgow City Council)

Option 4: Two detention basins: at Inishail Rd. and adjacent to Gartloch Rd.

The contributing sub-catchments for the basins would be the same as in Option 3. Although the SUDS features selected are different, the sites are the same and therefore the conditions for access and topography would be same as that for Option 3. The total developed area of 23% would contribute to the attenuation volume, while 8% of the developed areas would contribute to the long term storage volume. Schematic plan for this option is shown in Figure 5-12.

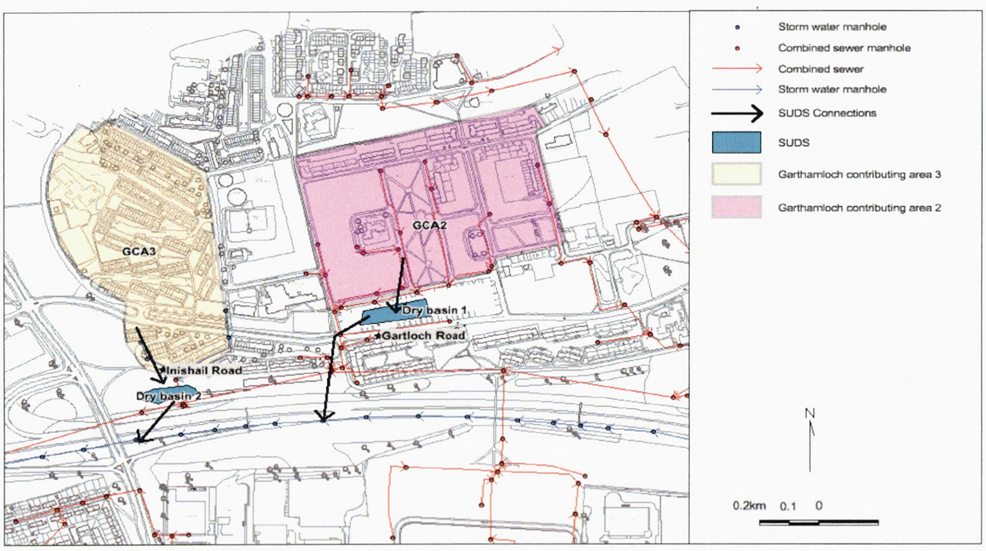


Figure 5- 12: Plan for Garthamloch SUDS option 4 (Two dry basins)

(Map source: Glasgow City Council)

Option 5: Two ponds: one at Inishail Rd. and another adjacent to Coxton Pl.

These proposed ponds would provide attenuation volume for 80% of the sub-catchment. Currently, combined sewers serve most of the proposed option and would require disconnection in surface water systems. The attenuated flow from the outlet could then join the surface water system beside the motorway as shown in Figure 5-13.

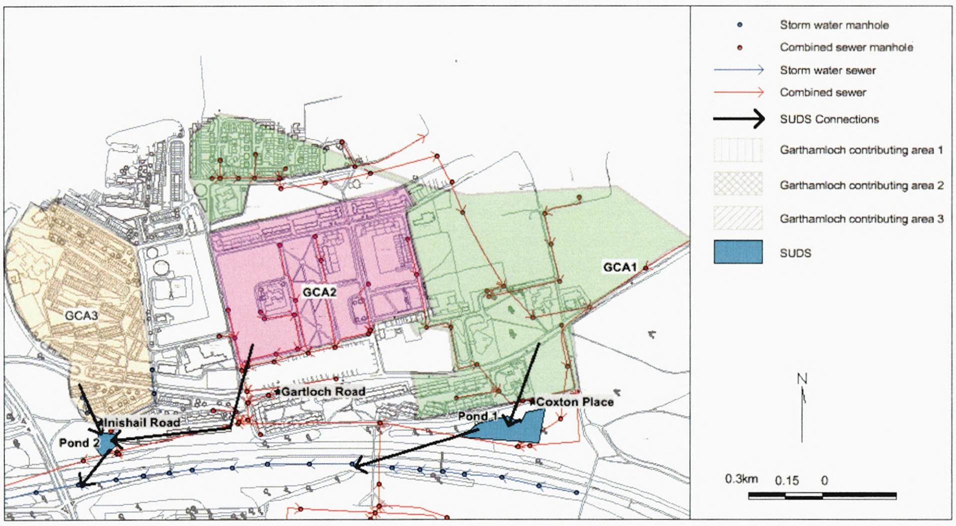


Figure 5- 13: Plan for Garthamloch SUDS option 5 (Two ponds)

(Map source: Glasgow City Council)

Summary

SUDS design factors associated with each option are summarised in Table 5-5 while the proportion of developed areas contributing towards attenuation volumes and long term volumes are shown in Table 5-6. The input parameters and the calculations involved are shown in Appendix B4.

Table 5- 5: Hydraulic design parameters of proposed SUDS for various options

Option No.	Option description	Contributing areas	Attenuation volume	Treatment volume	SUDS volume
		(ha)	(m^3)	(m^3)	(m^3)
1	One pond	11	1601	1161	3923
2	One wet basin	11	1155	1161	2316
3	Two ponds	7	1019	739	2497
		4	582	422	1427
4	Two dry basins	7	735	822	1557
		4	420	422	842
5	Two ponds	27	3929	2850.3	9629.8
		11	1600.7	1161.2	3923.2

(Design parameters and calculations of alternative options in Appendix B4)

Table 5- 6: Proposed proportion of developments contributing to attenuation and long term volumes

	Proportion of developed contributing to attenuation volume (%)	Proportion of developed contributing to long term volume (%)
Option 1	23	0
Option 2	23	10
Option 3	23	11
Option 4	23	8
Option 5	08	7

Skerryvore

A number of options for retrofit SUDS were considered for the sub-catchment. The options comprise potential SUDS in the Cranhill Park. The sites for retrofit SUDS were identified based on GIS data and site visits undertaken by the author. This section discusses storm water issues associated with each option.

Option 1: A Pond in Cranhill Park

The pond would be located in the southern part of the Cranhill Park near the entrance and would be accessible from Edinburgh Road. As the site is located at the downstream end of the sub-catchment, it would serve as an end of pipe attenuation control for the sub-catchment. The outlet of the pond would be connected to the Light Burn, which runs adjacent to the site. Overflows from the pond would be attenuated in a long term storage area, which would be designed to handle contribution from 70% of the developed areas. The plan for this SUDS scheme is shown in Figure 5-14.

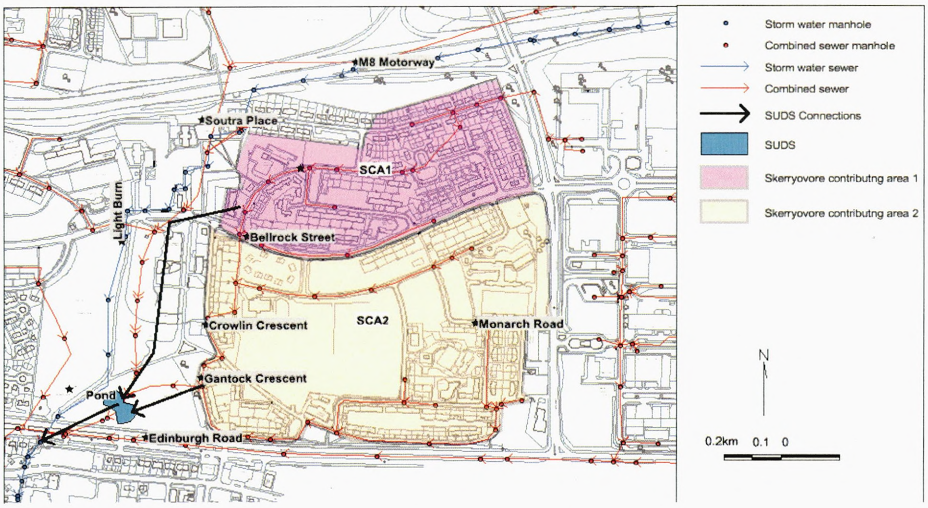


Figure 5- 14: Plan for Skerryvore SUDS option 1 (Pond)

(Map source: Glasgow City Council)

Option 2: A wet detention basin in Cranhill Park

As an alternative to the previous scheme, option 2, comprising an end of pipe wet detention basin, is proposed. This site would have the same contributing area and the outflow would connect to the watercourse. The basin would be designed for 10 year return period attenuation serving the whole subcatchment while 40% of impermeable area would contribute to the long term volume. The design parameters associated with this option are shown in Table 5-8. A schematic plan is shown in Figure 5-15.

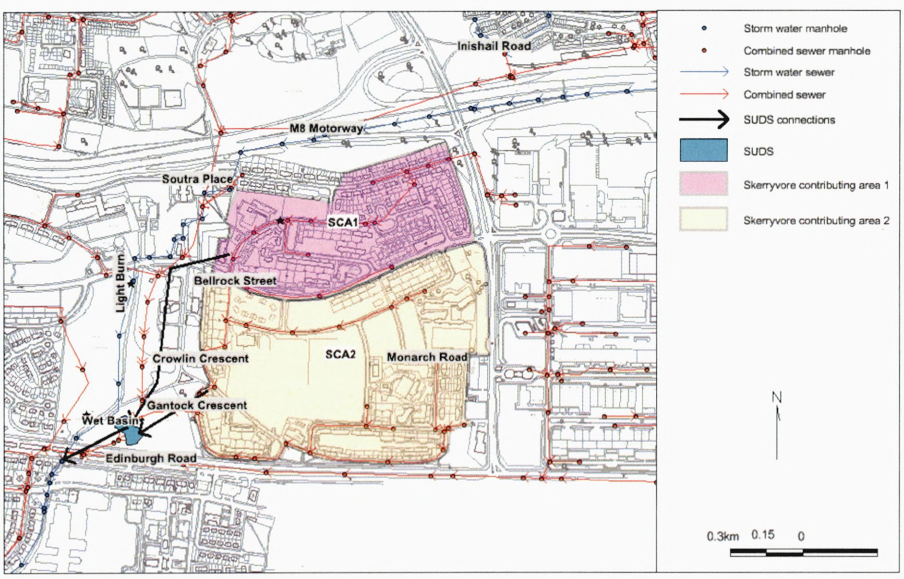


Figure 5- 15: Plan for Skerryvore SUDS option 2 (wet basin)

(Map source: Glasgow City Council)

Option 3: A dry detention basin at Skerryvore Place

A dry basin in central Cranhill Park is proposed as the third option. According to this option only the northern part of the sub-catchment would be draining to SUDS, while the southern part would continue to drain to the existing combined system. The basin would be designed with a high level weir so that overflows can be diverted in a long term attenuation area, releasing 2 litres/s/ha into the watercourse. Long term storage would be designed for 30% of the sub-catchment. Schematic plan for this option is shown in Figure 5-16.

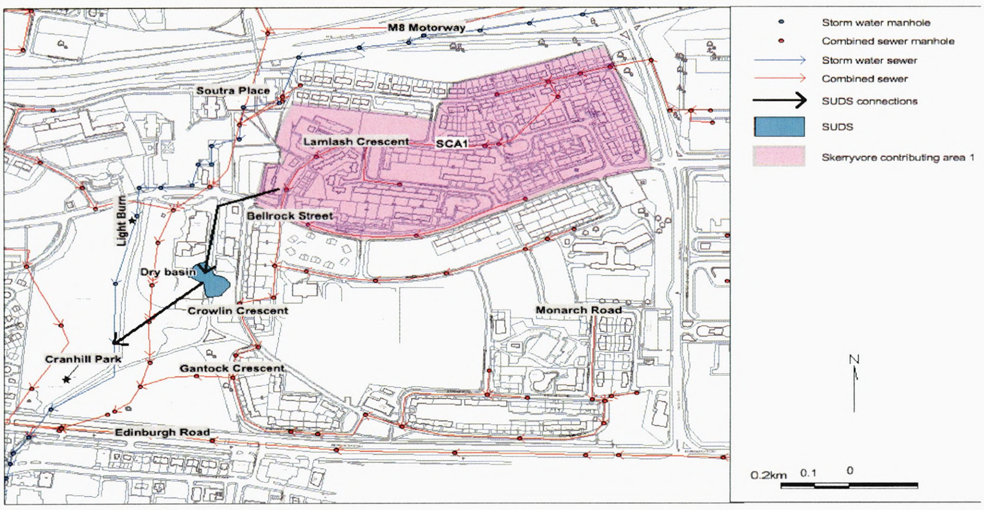


Figure 5- 16: Plan for Skerryvore SUDS option 3 (Dry basin)

(Map source: Glasgow City Council)

Option 4: A wet detention basin at Skerryvore and a pond at Cranhill Park

A wet detention basin is proposed at the centre of Cranhill Park as part of this option. This scheme would provide two levels of attenuation and treatment, and would have a contributing area of 24 ha. Overflows from the basin would be accommodated into a long term storage area (designed for 20% of contributing area) and drain into the watercourse at a rate of 2l/s/ha. Schematic plan for this option is shown in Figure 5-17.

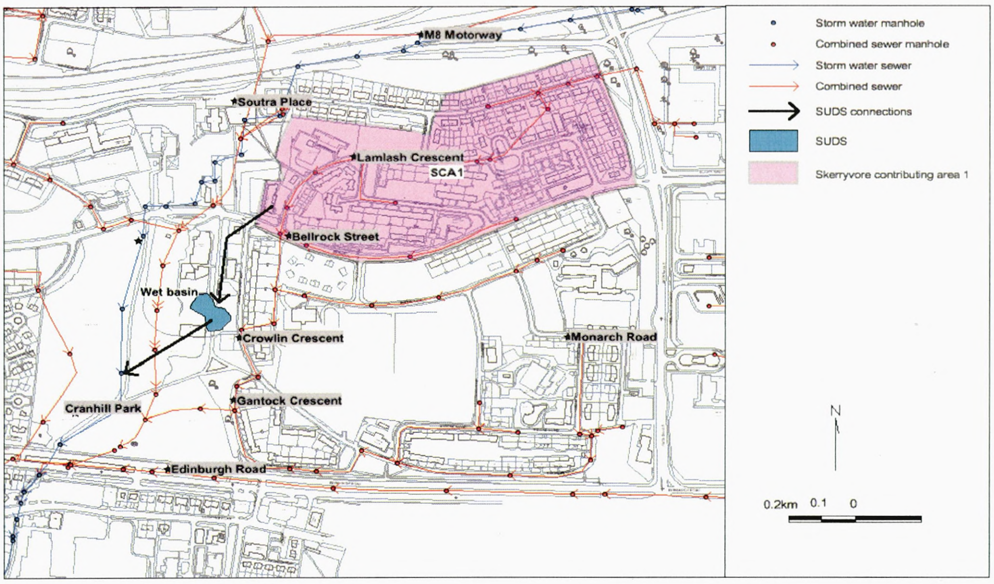


Figure 5- 17: Plan for Skerryvore SUDS option 4 (Wet basin)

(Map source: Glasgow City Council)

Option 5: Two wet basins and one pond at Cranhill Park

The basins are proposed to intercept runoff from two contributing areas. They would be located in the centre and south of the park respectively, and would drain into a pond. The basins are designed for 10 years return period events, while the pond would provide attenuation for exceedance of up to 30 year return period events. A long term volume for up to 10% of the contributing areas is attenuated upon overflow (after reaching 30 year peak flow) through a weir arrangement in Cranhill Park. Schematic plan for this option is shown in Figure 5-18.

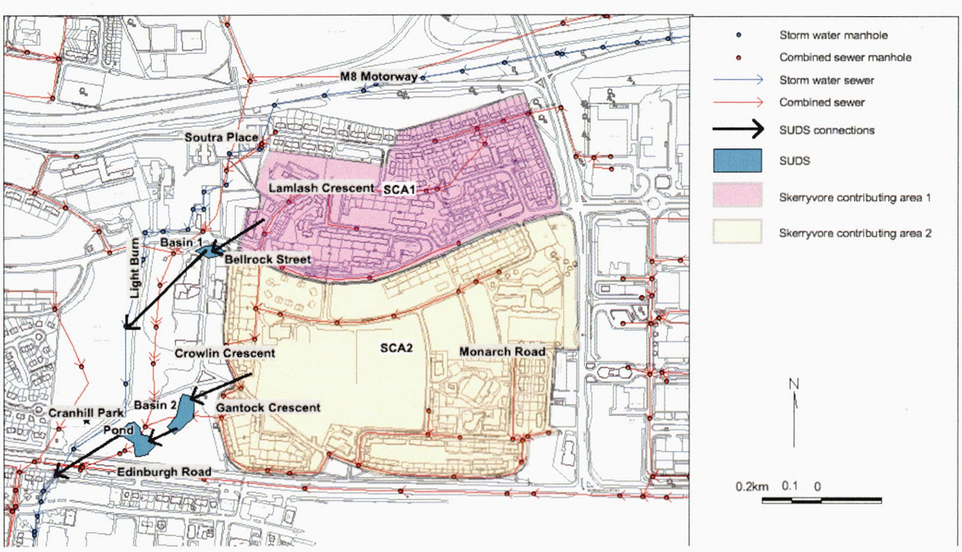


Figure 5- 18: Plan for Skerryvore SUDS option 5 (Two basins and a pond)

(Map source: Glasgow City Council)

Summary

SUDS design factors are summarised in Table 5-7, while Table 5-8 provides the proportion of developed areas contributing to attenuation and long term storage volumes.

Table 5- 7: Hydraulic design parameters of proposed SUDS for various options

Option No.	Option description	Contributing areas	Attenuation volume	Treatment volume	SUDS volume
		(ha)	(m^3)	(m^3)	(m^3)
Option 1	One pond	34	5003	3629	12262
Option 2	One wet basin	34	3610	3629	7239
Option 3	One dry basin	24	2520	2534	5054
Option 4	One wet basin	24	2520	2534	5054
Option 5	Two basins	24	2520	2534	5054
		10	1155	1161	2316

(Design parameters and calculations of alternative options in Appendix B4)

Table 5- 8: Proposed proportion of developments contributing to Attenuation and Long Term volumes

	Proportion of developed contributing to Attenuation Volume (%)	Proportion of developed contributing to Long Term Volume (%)
Option 1	100	80
Option 2	100	40
Option 3	70	30
Option 4	70	20
Option 5	100	10

Step 4b Assess recreation potential

Various indicators defined in chapter 4 were used to study the potential for recreation and are described here.

Garthamloch

Option 1: One pond at Inishail Road

The location of the proposed pond provides limited scope for recreation. However, the pond could have good aesthetics, which would encourage some walking and seating at the facility. The passive security of the site would be low as it would be located on the periphery of the housing estate. Development of a pond on the site could further enhance the biodiversity of the region. SUDS pond would introduce habitats for aquatic and semi-aquatic wildlife (CIRIA 2000) into the Garthamloch area which currently offers only the opportunities for terrestrial wildlife.

Option 2: One wet basin at Inishail Road

As the proposed site is the same as in the case of the first option, it will have limited access and low passive security. Its potential for multiple-use would also be limited, although the basin could be designed as an amenity area.

The proposed wet basin would have good ecological potential. Vegetation could comprise grasses, shrubs and some trees. Some presence of water during storm events would encourage greater diversity of plants at the bed of the basin.

Option 3: Two Ponds: one at Inishail Rd. and another adjacent to Gartloch Rd.

Both ponds are accessible, as they are located near roads and are on public land. The pond at Gartloch Road would have a high amenity value as it is located in the central location of a housing estate. This location has higher connectivity with houses, schools, green spaces and has good potential for multiple-uses, such as walking, sitting, picnic areas and fishing. The site would provide good passive surveillance for the safety of the users. The other pond site located at Inishail Road is situated towards the outer part of the housing estate and does not provide good passive surveillance. The second site would not offer good connectivity and access to residents.

The two ponds would enhance the ecological potential of the sites. Vegetation, such as trees, shrubs, grasses and aquatic plants, could be promoted at the sites. These areas would also attract a variety of wildlife, including fish, amphibians, reptiles, birds and mammals.

Option 4: Two detention basins: one at Inishail Rd. and another adjacent to Gartloch Rd.

Wet detention basins at the proposed sites would provide similar amenity benefits. However, due to the lack of a sufficiently large visible water feature, there would be a reduced amenity value. Facilities for walking and seating could also be developed at the sites. The basins would have less ecological potential than the ponds as the type of vegetation and wildlife would mainly be terrestrial.

Option 5: Two ponds: one at Inishail Rd. and another adjacent to Coxton Pl.

The proposed ponds would provide multiple benefits. Lying in the green corridor along the motorway, they would enhance biodiversity in the area. Dense vegetation around the pond would help to conceal the motorway and encourage walking along the banks of the pond. However, safety perception would be an important concern due to existence of lower passive surveillance and the hazard of permanent pools of water.

Skerryvore

Option 1: Pond in Cranhill Park

The proposed pond site would provide a high amenity value. As the site is located at the entrance of an already popular park with high connectivity, it can be developed as a multi-use site, with walking, seating, picnicking, playing and fishing facilities. Situated at the entrance to the park, the location also provides a good amount of passive surveillance.

This option would also enhance the biodiversity of the park. Development of the pond would add aquatic and semi-terrestrial vegetation to the site, which currently comprises mainly trees and grasses with some shrubs.

Option 2: Wet detention basin in Cranhill Park

Although a wet basin would have similar passive security and connectivity to the site, it would have reduced appeal due to lack of water visibility. The site is well connected, with footpaths to neighbouring housing estates and to Edinburgh Road. It could also have some multiple use facilities for playing, walking and seating.

The basin would encourage growth of various types of vegetation and wildlife. A wet basin would provide a good environment for aquatic and semi-aquatic plants and animals, as well as terrestrial species. The site would have three types of ecosystems: water, marsh and soil.

Option 3: Dry detention basin near Crowlin Crescent

A dry detention basin at Crowlin Crescent would have a low aesthetics. However the site has high accessibility and connectivity to housing and institutional areas. It is proposed for multifunctional use for attenuation and as a play area. The site provides good passive surveillance as it is located in the vicinity of the housing estate.

The existing ecological status would not change as a result of the proposed dry basin. However, additional planting of trees and shrubs would enhance the biodiversity of the site.

Option 4: A wet detention basin near Crowlin Crescent

A wet basin located at the central part of the sub-catchment would provide good amenity and aesthetic value to the park. The site for the basin is well connected with Bellrock Street and, hence, would facilitate easy access for maintenance and recreation. This basin could promote a variety of native plant growth and related wildlife. The site would be limited passive surveillance due to its distance from nearby buildings.

Option 5: Two wet basins and one pond at Cranhill Park

Two wet detention basins and a pond at Cranhill would significantly enhance the recreational opportunities in the sub-catchment. The amenity benefits of the scheme for pond would be same as option 1. In addition the scheme would provide the additional amenity benefits of the wet detention basin at Skerryvore Place. One basin site lying in the centre of the park would be connected to Bellrock Street, while the other basin would be accessible from Crowlin Crescent. Therefore, the site would have multiple uses, such as walking, seating, and playing.

The proposed option would create significant ecological opportunities. The scheme would encourage aquatic, semi-aquatic and terrestrial plants and animals. It would also enhance development of a green network to link the park and the housing estate; thereby creating more opportunities for species growth in the catchment.

Discussion to stage 4

There are various possibilities for planning of SUDS within subject sub-catchments. The options present in parks provide opportunities for linking with park activities while SUDS options in residential areas provide opportunities for local recreation. This approach of SUDS planning which entails linking it to the surrounding context would also fulfil the policy requirements set out in PPS 17 and SPP.

The lack of green spaces in Cardowan indicates the need for development of more green spaces during future redevelopments in the area. This will create possibilities for integrated storm water management in the sub-catchment and further reduce the risk of flooding.

5.6 STAGE 5: HYDRAULIC EVALUATION OF SUDS OPTIONS

The effect of retrofit SUDS was modelled for two sub-catchments: Garthamloch and Skerryvore are presented here. As no SUDS options were feasible in Cardowan, there was no hydraulic evaluation carried out. Step 5a describes the model modifications carried out to study several scenarios based on the options developed in stage 4. Rainfall data used for running the model is provided in step 5b while 5c illustrates the reduction of 30 yr peak flows in comparison to existing 30 yr peak flows of several SUDS options and optimum scenarios. Hydrographs representing reductions of peak flows for 10, 30 and 200 yrs are presented in Appendix B5.

Step 5a Model modifications to represent SUDS options

The hydraulic model used in stage 2 was modified to represent the effect of retrofit SUDS. Storage and treatment volumes as determined in stage 4 were added to the disconnected sub-catchments to indicate the impact of SUDS. Separate versions were developed for each SUDS option to analyse the benefits of providing attenuation storage.

Garthamloch

Five variations for the model for Garthamloch were created to represent the SUDS options. The combined sewer areas of Garthamloch was disconnected from the existing system and connected to the motorway storm drainage. Storage nodes were selected to represent the ponds and basins. The outflow from the SUDS was throttled using orifice to reduced values as shown in Table 5-9. The overflow from the SUDS devices were connected to long term volume storage using overflow weirs. The storage in these long term storage areas mobilised only during extreme events when overflow weirs of SUDS became operational. The discharge from the long term flow into the receiving was also restricted using levels

Table 5- 9: **Calculations for individual SUDS Options in Skerryvore**

Model Option	1	2	3		4		5	
	Pond	Wet basin	Pond 1	Pond 2	Basin 1	Basin 2	Pond 1	Pond 2
SUDS discharge (l/s)	81	81	51	29	51	29	198	81
LTV discharge (l/s)	0	10	8	3	4	4	48	19

Skerryvore

Five variations of the SUDS model were developed for Skerryvore to represent the five options identified in section 5-5. The representation of SUDS and outflow and overflow arrangements were similar to that in Garthamloch. The limiting discharge from SUDS and the long term storage area for the options in Skerryvore are represented in Table 5-10.

Table 5- 10: **Calculations for individual SUDS Options in Skerryvore**

Option	1	2	3	4	5		
	Pond	Wet basin	Dry basin	Wet basin	Wet basin 1	Wet basin 2	Pond
SUDS discharge (l/s)	252.0	252.0	175.9	175.9	175.9	73.3	252.0
LTV discharge (l/s)	55.0	27.5	20.6	13.8	6.9	6.9	0.0

Step 5b Running simulations

The modified model was run against 10, 30 and 200 years design storms of various return periods. The critical duration return period was established after examining the flooding from various events i.e. 15 min, 30 min, 1hr, 2hr, 3hr, 6hr, and 12 hr. Peak flows were determined for 10, 30 and 200 yrs critical events.

Step 5c Comparisons of current peak flows and SUDS options

The results were studied to assess the possible release in sewer capacity (enhancement of capacity due to disconnection of runoff from the sewer system) as well as a decrease of flooding at the catchment scale. A comparison of existing peak flows with that from various SUDS scenarios is presented in Figure 5-19 and Figure 5-20 for 30 yr return period events.

Garthamloch

The comparative hydrographs show that Option 5 produced lowest peaks. This is due to the maximum contribution of impermeable area to SUDS for this Option (70 % of the total impermeable area) while contribution of impermeable areas in other options (23 % of the total impermeable area) are much lower. This is shown in Table 5-6 in section 5.5.

Analysis of the hydrograph showed lower sensitivity to type of SUDS in various SUDS options but showed more sensitivity to peak flow reduction for higher return periods. For example, hydrographs for option 1 and 2 were similar (refer to Figure 5-19). The model however showed maximum sensitivity between the amounts of area disconnected with the attenuation volume (refer to Figure 5-19). When the area serving SUDS increased to become more than two-thirds the peak flow also reduced approximately by similar proportions (Option 5). The results for attenuation volumes showed sensitivity to the amount of contributing areas disconnected. Analysis of long term volumes showed lower sensitivity to the changes in flow hydrograph. For example, the 200 yr hydrograph (refer to Appendix B5 Figure 3) long term storage did not show a significant reduction in flow in relation to the increased area contribution, however the hydrograph did show changes in the profiles causing peak flow for reduced durations.

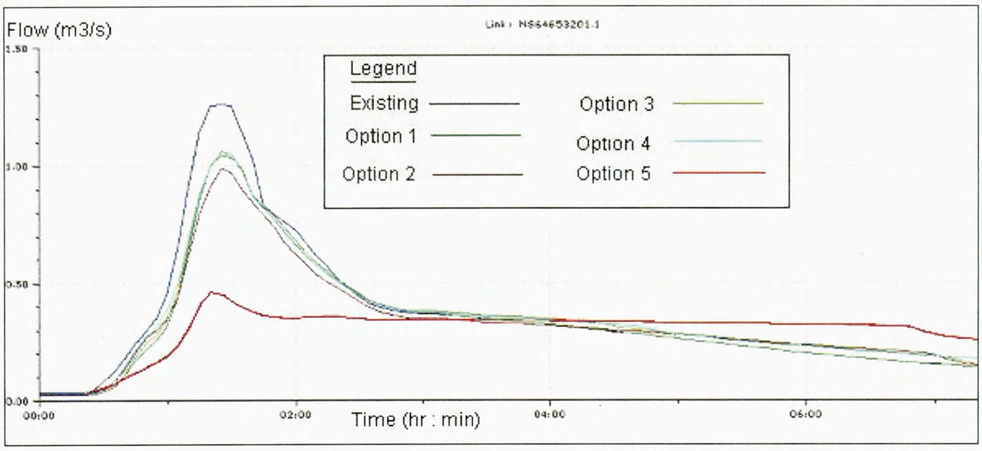


Figure 5- 19: **Flow hydrographs of various SUDS options for the critical event of 30 yr 120min in Garthamloch**

Skerryvore

All options show significant attenuation in the case of Skerryvore as a significant part of the impermeable areas for all the options are contributing to SUDS. In Options 1, 2 and 5, a hundred percent of impermeable area in the sub-catchment is connected to SUDS, while for Options 2 and 3, seventy percent of the impermeable area is connected to proposed SUDS.

The hydrograph shows lower sensitivity to the type of SUDS but showed more sensitivity to peak flow reduction for higher return periods. The hydrograph also showed more sensitivity between the amount of area disconnected with the attenuation volume (refer to Figure 5-20). The area was decreased in Option 3 and 4 in comparisons to Options 1, 2 and 5 by 30% and the results show an increased peak flow of about 13%. The results for attenuation volumes showed sensitivity to the amount of contributing areas disconnected. Analysis of the hydrographs for changes in the long term volumes however showed lower sensitivity (refer to Appendix B5, Figure 6).

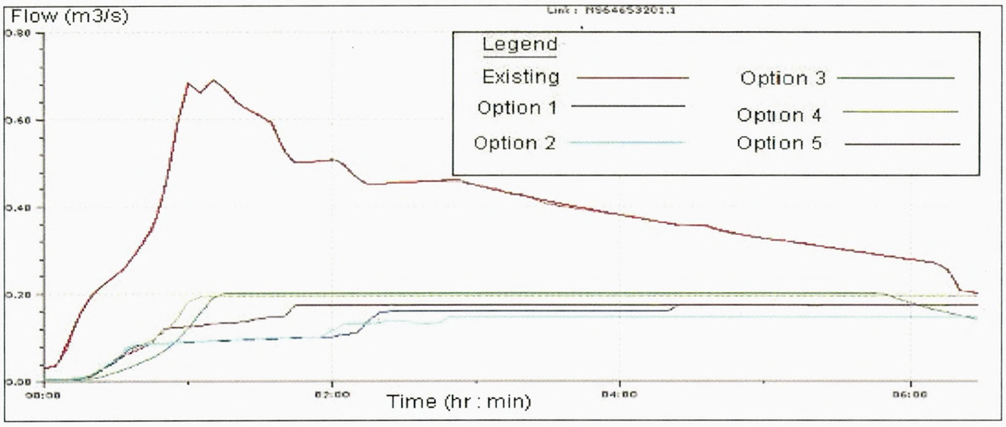


Figure 5- 20: **Flow hydrographs of various SUDS options for the critical event of 30 yr in Skerryvore**

Discussion to stage 5

SUDS options developed by disconnecting larger contributing areas generated more flood attenuation. For example, option 5 in Garthamloch provided maximum flood attenuation as significant portion of the impervious areas is proposed to be disconnected. In Skerryvore, most of the options have similar contributing areas and hence similar attenuated flow rates.

5.7 STAGE 6: INTEGRATED EVALUATION OF SUDS OPTIONS

The SUDS options developed in stage 4 and tested in stage 5 are evaluated in this section. It comprise of two steps: 6a and 6b, where 6a describes integrated scoring of SUDS options and 6b describes selection of final preferred option. The steps for evaluating integration of SUDS with green space planning are described below for each sub-catchment.

Step 6a Scoring of SUDS options

The various options, identified in stage 4, for planning of retrofit SUDS are scored, using the evaluation matrix developed in Chapter 4. This matrix comprises recreation and storm water indicators for integrated evaluation of the alternatives, the scoring mechanism shows the sensitivity of scores to changes in location of SUDS, types of SUDS and size of SUDS (increasing contributing areas). The calculations and explanations for the scoring are provided in Appendix B6. The scores for the two sub-catchments are summarised in Table 5-11 and Table 5-12.

Table 5- 11: Application of integrated scoring matrix for retrofit SUDS options in Garthamloch

(Calculations for obtaining the scores in Appendix B6)

Option No.	1	2	3	4	5
Indicators					
Access	0.6	0.6	1.8	1.8	0.6
Water visibility	2.1	1.4	2.1	0.7	2.1
Aesthetics	2.1	0.7	2.1	0.7	2.1
passive security	0.6	0.6	1.8	1.8	0.6
Multi-purpose	1.6	1.6	1.6	0.8	1.6
Safety	0.8	1.6	0.8	2.4	0.8
Ownership	2.1	2.1	2.1	2.1	2.1
Flood return period	5.1	3.4	5.1	3.4	5.1
Attenuation volume	1.6	1.6	1.6	1.6	4.8
Long term storage	1.6	1.6	1.6	1.6	4.8
total score	18.2	15.2	20.6	16.9	24.6

Preferred solution

Table 5- 12: Application of integrated scoring matrix for retrofit SUDS options in Skerryvore

(Calculations for obtaining the scores in Appendix B6)

Option No.	1	2	3	4	5
Indicators					
Access	1.2	1.2	1.2	1.2	1.2
Water visibility	2.1	1.4	0.7	1.4	2.1
Aesthetics	2.1	1.4	0.7	1.4	2.1
passive security	1.2	1.2	1.2	1.2	1.2
Multi-purpose	2.4	2.4	2.4	2.4	2.4
Safety	0.8	1.6	2.4	1.6	0.8
Ownership	2.1	2.1	2.1	2.1	2.1
Flood return period	5.1	3.4	3.4	3.4	5.1
Attenuation volume	4.8	4.8	4.8	4.8	4.8
Long term storage	4.8	3.2	1.6	1.6	1.6
total score	26.6	22.7	20.5	21.1	23.4

Preferred solution

Step 6b Final preferred SUDS scheme

This section evaluates the various preferred options as identified in step 6a. The final options were selected based on the scores of the options in the earlier step.

Garthamloch

The five options were compared and evaluated for the various attributes of their indicators. The comparisons of scores showed that Option 5 was the preferred option on account of having maximum score due to favourable attributes of most indicators (Refer to Table 5-11). It comprised of two ponds attenuating maximum impermeable areas. Most options received lower scores due to low recreational values of detention basins; however option 3 comprising a pond option was allotted a similar recreational score to option 5 due to similar attributes but a lower storm water score on account of lower attenuation potential.

The proposed solution comprises two ponds in the southern part of the sub-catchment. Both ponds would require disconnection of combined sewer areas. The proposed drainage pattern for the solution is shown in Figure 5-21. A photograph of the proposed location of the pond (Pond 2) at Inishail Road is presented in Figure 5-22. Pond 2 of the proposed solution will be accessible through a footpath as shown in Figure 5-22, however there is no existing road for wider accessibility. As the pond lies in an isolated area (behind the housing estate on Inishail Road).this option was given a low score for accessibility indicator. Due to visibility of water and complex vegetation structure it will have a higher amenity value. As the depth of water in the pond will be more than 1m there will be a higher perceived risk of safety, but the design specifications should ensure minimisation of this risk. The ponds should also encourage native vegetation and provide a variety of habitats to promote more wildlife.

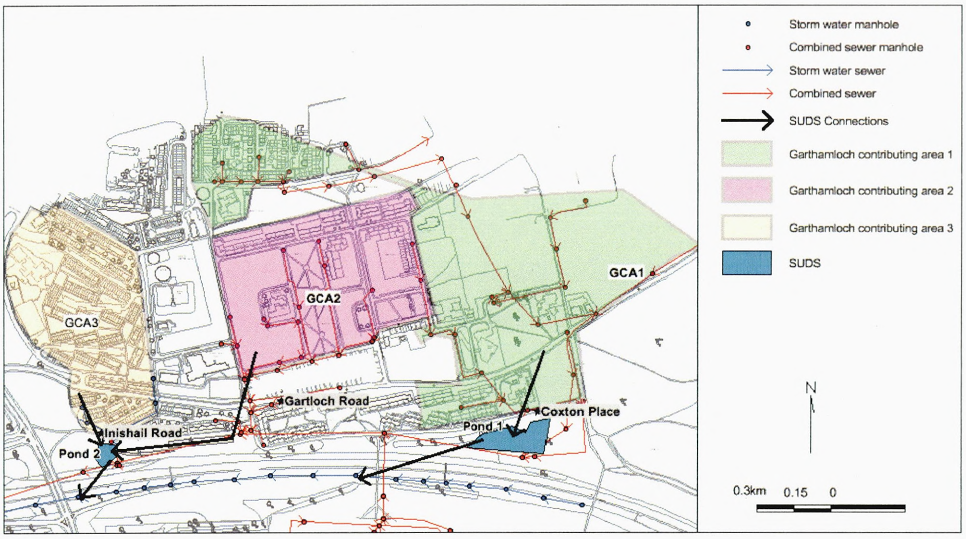


Figure 5- 21: Plan of the preferred option in Garthamloch

(Map source: Glasgow City Council)

Figure 5- 22: Site of the proposed Pond 2 in Garthamloch (shown by arrow)

(Source: Google Street view)

Skerryvore

Option 1 was the most preferred solution among the five options in Skerryvore (shown in Table 5-10). Option 1 provides greater disconnection of impermeable areas

(Table 5-12) as well as higher recreational scores to Options 2, 3 and 4 which are associated with detention basins. Option 5 comprising of a pond and two detention basins received the second highest scores but was score lower than option 1 due to its lower long term storage.

Option 1 comprises of a pond in the Park beside the culverted watercourse, Light Burn. The housing estate north of Bellrock Street as well as the area south of Bellrock Street would drain into the pond. The flow from the pond would drain into the Light Burn watercourse. Overall layout of the SUDS scheme is illustrated in Figure 5-23.

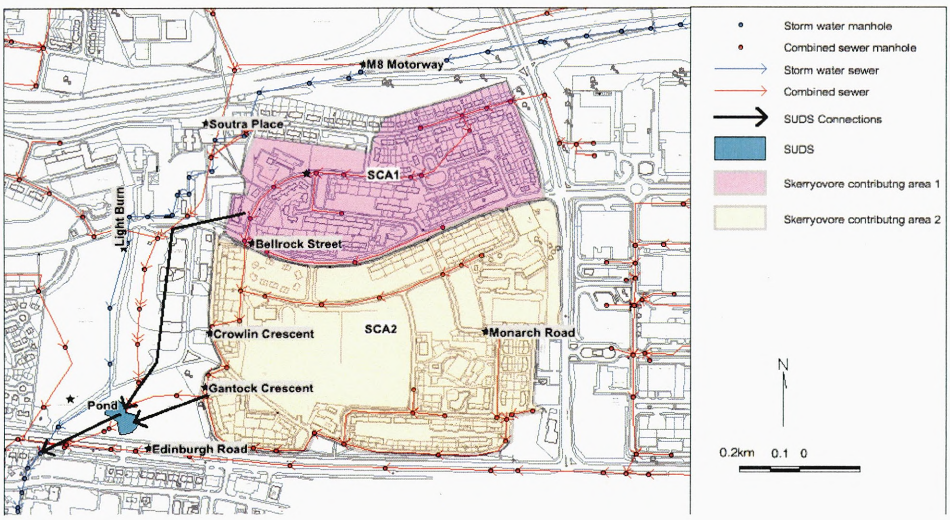


Figure 5- 23: Plan of the preferred option in Skerryvore

(Map source: Glasgow City Council)

The presence of the pond near the entrance to the park would be a significant attraction. Recreational activities, such as walking and playing in the park, would be boosted by the increased attention of the neighbouring residents. The roadside location of the pond would provide good passive security as well. Provision of benches around the pond would enable the residents to relax and enjoy the beauty associated with the pond wildlife.

The proposed pond in Cranhill Park offer significant biodiversity opportunities. Cranhill Park is currently planted mainly with mown grass, with some trees and patches of other herbaceous vegetation which offers limited habitat potential. Once a pond is developed in the park, it would provide a habitat for a variety of aquatic plants and animals. The presence of the green corridor would cause dispersion of species in the catchment, thus further enhancing the biodiversity and amenity of the area. A photograph of the site in Figure 5-24**Error! Reference source not found.** shows that it already has some vegetation.

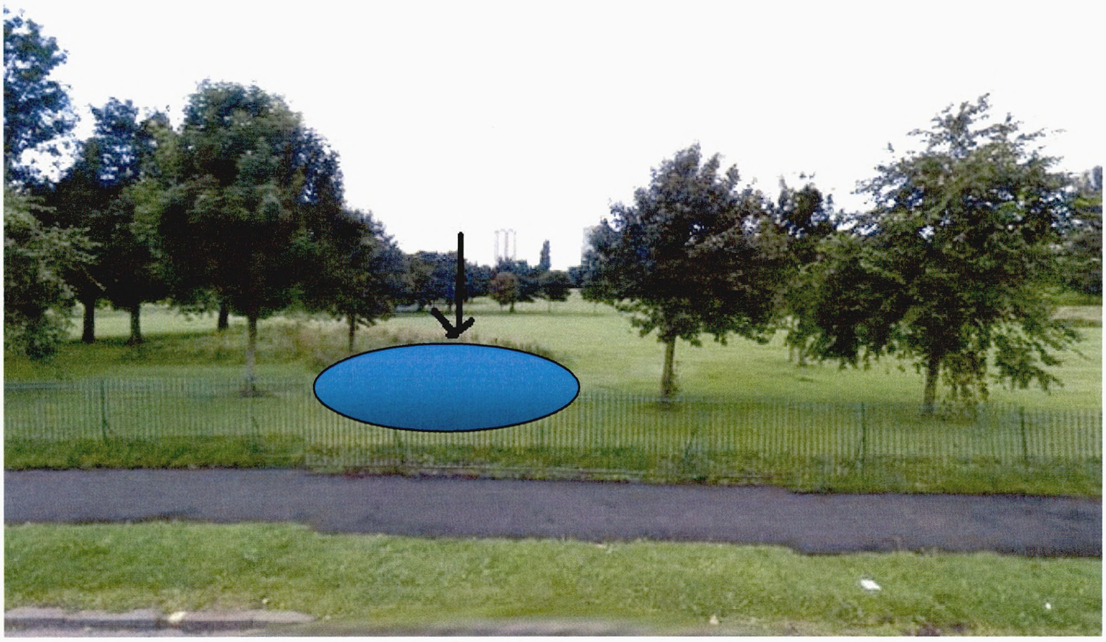


Figure 5- 24: Location of proposed Pond in Cranhill Park (shown by arrow)
(Source: Google Street view)

Discussion to stage 6

Indicator values in Table 5.7 represented that a variation of SUDS schemes so that the sensitivity of the scoring system could be assessed. Two indicators water visibility and safety have three attribute variations while four recreational indicators had two attribute variations. One indicator, ownership was not varied as all SUDS options were located on public land. Private land was not considered as they were fragmented into house gardens which were smaller than the size required for the proposed basins and ponds. Each of the storm water management indicators had two attribute variations as limited sites were suitable for the planning of SUDS.

The selected option for Garthamloch had higher storm water scores than other options. Similarly, in Skerryvore sub-catchment option 1 which had higher storm water scores was selected as the preferred option. Further, as each storm water indicator had a higher normalised weighting than recreational indicators options with higher storm water indicator scores were more likely to become the preferred options.

In Garthamloch storm water management indicator score was higher than recreational scores for three options: Option 1, 2 and 5. However, for options 3 and 4, the total recreational scores were higher than the storm water management scores.

Sensitivity assessment of the recreational and storm water indicators is carried out in section 7-3. Total recreational and storm water scores have been compared for existing scenarios as well as the potential scenario of increasing and decreasing the scores by10% and 20%. The development of several options was itself carried out to study the sensitivity of all indicators. Section 7-5 discusses the sensitivity of existing indicators both recreational and storm water towards maximising the total scores in the four options of the two sub-catchments studied.

The scoring tool provided a method to evaluate the various parameters for each option. This method also provides an opportunity for balancing the amenity requirements of urban planning with the needs of storm water management. This is in contrast to the previous SUDS planning approach where evaluation of recreational criteria was not adequately defined and hence often resulted in non aesthetic SUDS with little recreational value as noted by Ferguson (1991).

5.8 DISCUSSION

The catchment showed good overall potential for integrated planning of storm water management. While Skerryvore and Garthamloch, with a significant amount of open spaces, provided good opportunities for retrofitting SUDS within the sub-catchments, there were no opportunities for the same in Cardowan. Site analysis also showed that there could be recreational and associated biodiversity benefits from these schemes.

The risk of flooding in the three sub-catchments (described in section 5.3) was associated with land use distribution. A lower proportion of green spaces in the lower reach of the catchment caused greater risk and vulnerability to flooding. In Cardowan, there are negligible green spaces, whilst in Skerryvore and Garthamloch, where the risk of flooding is lower, there are substantial green spaces. Therefore, the distribution of green spaces is not water compatible. Planning for future regeneration, therefore, should focus on creating green spaces within Cardowan in order to further reduce the risk of flooding.

Assessment of green spaces (discussed in section 5.4) in the catchment shows various possibilities for integrating SUDS and recreational opportunities. The evaluation matrix shown in step 3d of section 5.4 also showed that some green spaces were more useful for planning retrofit SUDS than others. The matrix showed the variation in SUDS planning opportunities based on distribution of green spaces as well as quantity of green spaces. For example, Skerryvore with a public park in low lying area downstream of housing estate showed maximum opportunities for integrating SUDS sites and recreational planning while there were little opportunities for SUDS sites in Cardowan.

Planning of SUDS options in section 5.5 showed they have different recreational attributes considered at the design stage. At this stage various types of integration approaches can be conceived. For example, in Garthamloch sub-catchment option 1, the pond was conceived as mainly for storm water management and ecological functions, however in Skerryvore option 1, the pond was conceived with additional benefits such as paths for walking, seating areas, and meeting areas.

Results from the hydraulic model analysis (described in section 5.6) showed a variation in peak flow reduction according to the amount of storage provided and the return period mitigation. This reduction of peaks was more prominent when there is significant increase in the areas contributing to SUDS as shown in Figure 5-19 (showing significant reduction in peak flow for SUDS option 5 in comparison to other options).

Analysis in section 5.7 indicated that the evaluation tool discussed in chapter 4 indicates potential for evaluating various SUDS in order to arrive at a more holistic SUDS option. This was illustrated in Table 5-11 and Table 5-12, which show that the final score for each SUDS option was sensitive to the various recreational and storm water management indicator scores. However, the final scores selected in Table 5-11 and 5-12 shows greater sensitivity towards changes in storm water management indicators. This was due to the higher weightings of the individual storm water indicators in comparison to the recreational indicators. The final score was a trade-off between recreation and storm water management. For example, in Table 5-11, option 5 was selected as the preferred option as it received a higher overall score than other options although the recreational score was lower than option 3.

Application of the framework indicated potential for its wider use as the framework was developed using previous research and standards in the areas of green space planning and storm water planning. In order to test the application of the framework in another case study area, a catchment in Renfrewshire was selected as it lies in a different location and is subject to different local and regional plans. This second case study is presented in Chapter 6.

6 APPLICATION OF THE PROPOSED FRAMEWORK FOR INTEGRATING GREEN SPACE AND WATER PLANNING IN SPATESTON CATCHMENT

6.1 INTRODUCTION

This chapter aims to test the application of the conceptual methodology in the Spateston catchment in Paisley after its application in the Light Burn catchment. The second case study assesses its more generic applicability. The catchment is situated in the south west of Johnstone in Renfrewshire, Scotland and is well connected by road and rail (location plan in Figure 6-1). The study catchment is named 'Spateston' after the watercourse flowing through it.

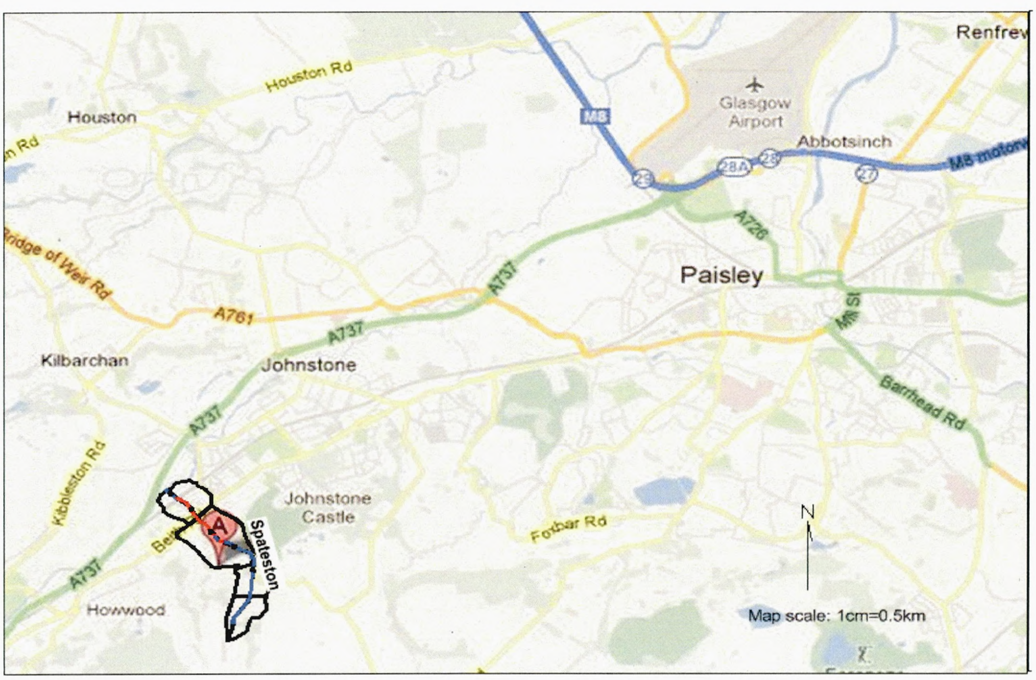


Figure 6- 1: Location of Spateston Burn catchment

(Source: Google maps)

The application of the methodology required detailed analysis to test various options. Thus, this chapter provides an overview of the issues for the whole catchment but detailed analysis for a sample of three sub-catchments.

The sample sub-catchments (shown in Figure 6-2) were:

1. Martlet
2. Heron
3. Ettrick

These sub-catchments were selected to test the framework and tool developed in chapter 3 and 4. The considerations for selecting the three sub-catchments have been discussed in section 4-10, chapter 4.

The structure of this chapter is similar to Chapter 5. Application of the methodology is described in sections 6.2 to 6.7. Stage 1 presented in section 6.2 describes the land use and drainage patterns of the Spateston catchment. Section 6.3 relates to the hydraulic evaluation and flood risk assessment. Green space assessment associated with stage 3 of the conceptual framework is described in section 6.4. Implementation of stage 4 of the framework is reported in section 6.5 of this chapter. Results for evaluation of SUDS related to flood management are presented in section 6.6 and are linked to stage 5. Integrated evaluation of green space planning with SUDS, associated with stage 6 of the framework, is taken up in section 6.7. Section 6.8 provides an overall discussion of the results from earlier sections. Supporting data and calculations are presented in Appendix C1 to C6.

6.2 STAGE 1: CATCHMENT LAND USE AND DRAINAGE ASSESSMENT

This stage deals with land use and drainage assessment for the Spateston catchment.

Step 1a Demarcate catchment and sub-catchment boundaries

The catchment was divided into eight sub-catchments, as shown in Figure 6-2. The delineation of the catchment and sub-catchment was carried out using topographic maps provided by Renfrewshire Council. Apart from topographic maps, other information such as drainage network, property boundaries, drainage from roads and other paved areas were also considered to demarcate the sub-catchments. The data for this analysis was provided by Renfrewshire Council. Site visits were also undertaken to study the topography and the drainage patterns in the catchment.

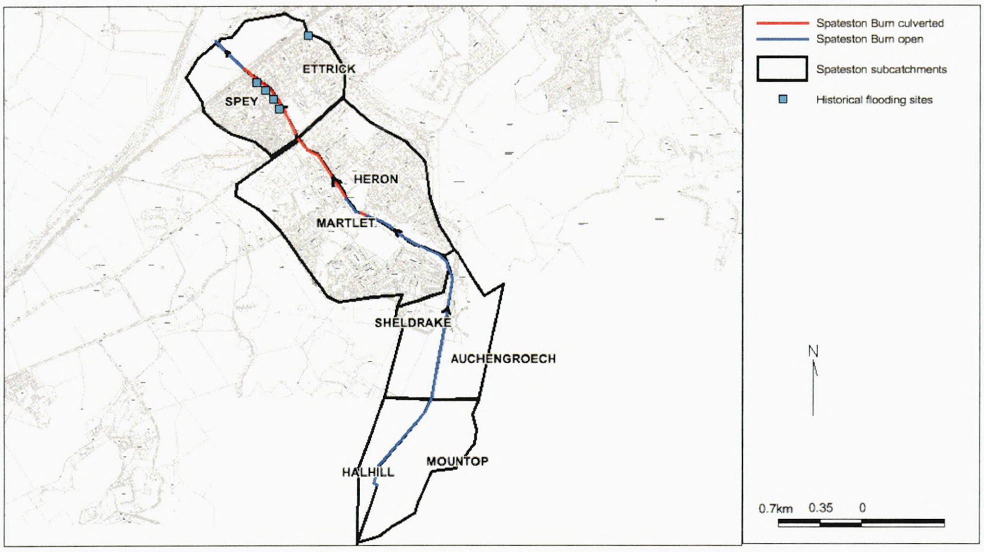


Figure 6- 2: Division of Spateston Burn catchment into seven sub-catchments
(Map source: Renfrewshire Council)

Step 1b Study catchment characteristics

Spateston Burn is a tributary of Black Cart and is a steeply sloping catchment. The area is served by separate sewers, which outflow into the Spateston Burn. The upper part of the catchment is largely undeveloped; but the lower portion of the catchment is intensively developed. Spateston Burn has both culverted and unculverted sections. It is culverted in the lower part of the catchment, while it is open in the upper portion. The culvert has reduced recreational opportunities in developed parts of the catchment, as shown in Figure 6-3.

Figure 6- 3: Open and Culverted sections of Spateston Burn

In this catchment, anecdotal evidence from residents suggests that overland flow is a major cause of flooding, in addition to the constraints of drainage capacity. This catchment has steep drops throughout the length of the catchment, which potentially makes the area prone to flash flooding. Flooding is also exacerbated by culverting of the watercourse in its lower stretch as well as development of properties in very close proximity (as shown in Figure 6-2).

Step 1c: Study land use characteristics

Land use in the catchment is a mix of residential, institutional, commercial and green space, and agricultural. Housing in the area typically comprises tenements, tenement blocks, and semi-detached houses. This spatial distribution of land use is presented in Figure 6-4, while the proportions of land use are shown in Table 6-1.

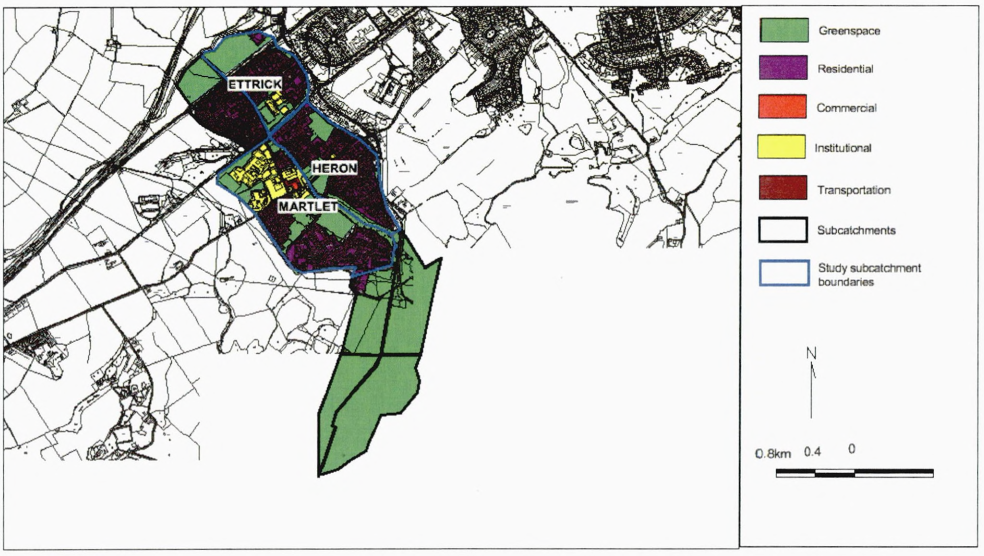


Figure 6- 4: Land use in Spateston Burn Catchment

(Map source: Renfrewshire Council)

Table 6- 1: Distribution of land use in the Spateston Catchment

	Area (ha)	Percentage
Open space	113	36
Commercial	1	0
Institutional	23	7
Residential	131	41
Transport	49	15
	317	100

The proportion of land uses within each sub-catchment was also studied and is shown in Figure 6-5 which shows that the four upper sub-catchments: Sheldrake, Auchengreoch, Halhill and Mountop, are predominantly rural, while the other four sub-catchments in the lower areas are urbanised.

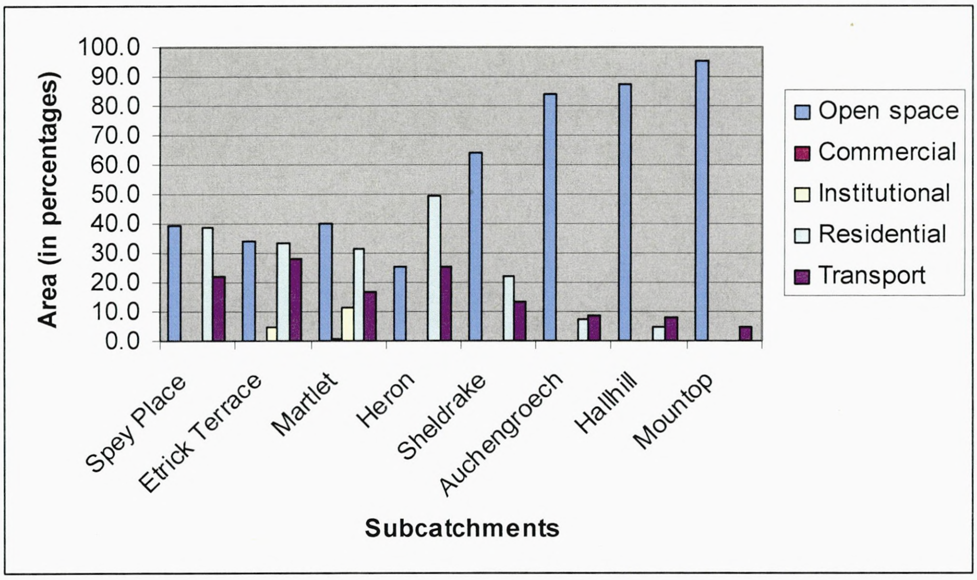


Figure 6- 5: Distribution of land uses in each Spateston sub-catchments (in percentages)

Green spaces are present in the form of stream corridors, playing fields and other amenity areas; however, they are not uniformly distributed in the catchment. Detailed analysis of green spaces is presented in section 5.4 (stage 3), which also examines the topography of potential SUDS sites.

Step 1d Drainage patterns in selected sub-catchments

Drainage characteristics of sample three sub-catchments were studied as described below.

Martlet

All developments are served by separate sewer systems in these sub-catchments. These separately sewered areas drain directly into the Spateston Burn which is mainly open in this reach, but becomes culverted in the lower portion of the sub-catchment. There is a risk of blockage due to a sudden change in gradient when the watercourse enters a culvert through a grill.

A total length of 300m is culverted as the stream enters the flood plain in the lower reaches. The culvert lies at an average depth of 2.5m beneath the footpath, with housing estates on both sides. Due to the presence of open spaces adjacent to the watercourse, there is a potential for SUDS at several sites, as discussed in detail in Stage 4. The drainage layout for Martlet is presented in Appendix C1 Figure 6.

Heron

Separate sewers drain all the housing estates in this sub-catchment. There are four branches of separate sewers present in Tern Place, Falcon Road, Finch Place and Churchill Avenue respectively, and each branch drains directly into the Spateston Burn (refer to Appendix C1, Figure 12). This sub-catchment shares the same section of watercourse as Martlet, as it is located on its opposite side.

Ettrick

This sub-catchment is served by separate sub-catchments and is bordered by two river systems, Spateston Burn and Black Cart, and runoff from the catchment discharges into both of these water bodies. Currently, runoff from the developed area drains directly to the Spateston Burn, while the runoff from the greenfield areas drains mainly to the Black Cart River. The drainage layout for Ettrick is presented in Appendix C1 Figure 18.

Spateston Burn is culverted for a length of 361m while crossing through the residential estates of Ettrick; it then opens up before it joins the Black Cart. The average depth of the culvert is 2m and it is located underneath a footpath as it crosses the sub-catchment. There is very little potential for retrofitting SUDS as there are very few green spaces, as discussed in stage 3 in more detail.

Step 1e: Study detailed land use characteristics in selected sub-catchments: Martlet, Heron and Ettrick were selected for further detailed analysis.

1) Martlet

Martlet sub-catchment has an area of 24 hectares and has largely been developed as residential housing. There are 9.8 hectares of green field areas in this sub-catchment, comprising playing fields near schools, amenity areas, recreational areas, semi-natural and natural sites. Residential land uses comprise nearly 8 hectares, while another 3 hectares is institutional (used for schools). There are a total of 384 dwellings in this sub-catchment, comprising 182 semi-detached houses, with the remaining being detached housing. The land use spatial distribution is indicated in Appendix C1, Figure 1.

2) Heron

Heron is a mainly residential sub-catchment with a total area of 15.6 Ha. It contains residential, transportation and green space areas of 7.7 ha, 3.9 ha and 3.9 ha respectively. Tenements, terraced and some semi-detached dwellings are located in the various housing estates in the catchment. The areas beside the watercourse have native vegetation, while other open spaces contain mown grass. The land use spatial distribution is shown in Appendix C1, Figure 7 while the various categories of green spaces in the catchment are described in section 6.4 in detail.

3) Ettrick

Ettrick comprises a total area of 12.67 hectares, which is mainly developed for residential uses. The housing estate comprises terraced blocks with a total of 210 dwellings. There is also an old school that has now been regenerated. The lower part of the sub-catchment adjoining the Black Cart has remained undeveloped due to the presence of a railway line in the area, which reduces accessibility. This sub-catchment has 4.27 ha of open spaces, most of which lie around the railway line; the green space within the housing estate is limited to the school playgrounds and some incidental green spaces beside roads and car parks. The land use spatial distribution is indicated in Appendix C1, Figure 13.

Discussion to stage 1

Stage 1 showed the method for integrating development and drainage planning. As the selected sub-catchments, Martlet, Heron and Ettrick had different patterns of development; they were considered good candidates for analysing recreation and storm water management integration possibilities for diverse situations. Martlet had a park with several housing estates surrounding it; Heron had some amenity green spaces as well as a green buffer area adjoining the watercourse while Ettrick was the most developed with lesser green spaces than other two sub-catchments. Analysis of distribution of development also provided opportunities for linking with flooding in stage 2. The understanding of development patterns provide data for linking it to the green spaces assessment which is considered in detail in stage 3.

6.3 STAGE 2: HYDRAULIC ASSESSMENT

The current status of flooding was determined using a hydraulic model (discussed in Step 2a) for the three sub-catchments of Martlet, Heron and Ettrick. Hydrographs of various events at the downstream ends of these sub-catchments were also analysed so that reductions in peak flows could be compared with various SUDS options in stage 5. The hydrographs are shown in Appendix C2, while the assessment of flooding is presented in this section.

Step 2a Develop integrated model

The hydraulic model was developed by JBA consultants. This model is based upon the data provided by Scottish Water, Renfrewshire Council and other drainage consultants. It has been developed using the drainage software, Infoworks CS. This was an integrated model with both watercourse and the sewers (foul and surface water) represented within the model. . A soil type of category 4 was considered in the model as determined using FEH data.

Some changes were made in the model after obtaining it from the consultants. Drainage networks, belonging to the Spateston Burn catchment and other contributing areas, were extracted from the overall model of the drainage system which drained into the downstream wastewater treatment works. As the Spateston catchment had separate sewers draining the subcatchments into the Spateston Burn and the Black cart; extraction of the drainage network from the overall model would not have any hydraulic affect in the Spateston catchment. The model used flow survey data including rainfall data, flow data and dry weather provided by the modellers which flow was used to again verify the model so that it was deemed fit for the purpose of this research.

Step 2b Analyse flooding and peak flow from extreme events

The flooding from a 200 year event was assessed for the selected sub-catchments as follows:

Martlet Street

In Martlet Street, flooding is likely to be caused by surcharging from sewers on Spateston Road as well as one of the manholes near the secondary school. Based on the topography of the catchment the flood water would travel towards the lower end of Halhill Road, affecting some of the residential properties. Flooding is shown by light blue spots, while flood paths are shown by arrows in Figure 6-6. The modelled surcharging flows would drain into the green spaces and then into the watercourse based on the topography. As the model did not have the capability for overland flow predictions, the potential overland flow routes was judged using the topographical map in Appendix C2 Figure 4. Table 6-2 shows relationships between modelled flooding and vulnerability of land uses.

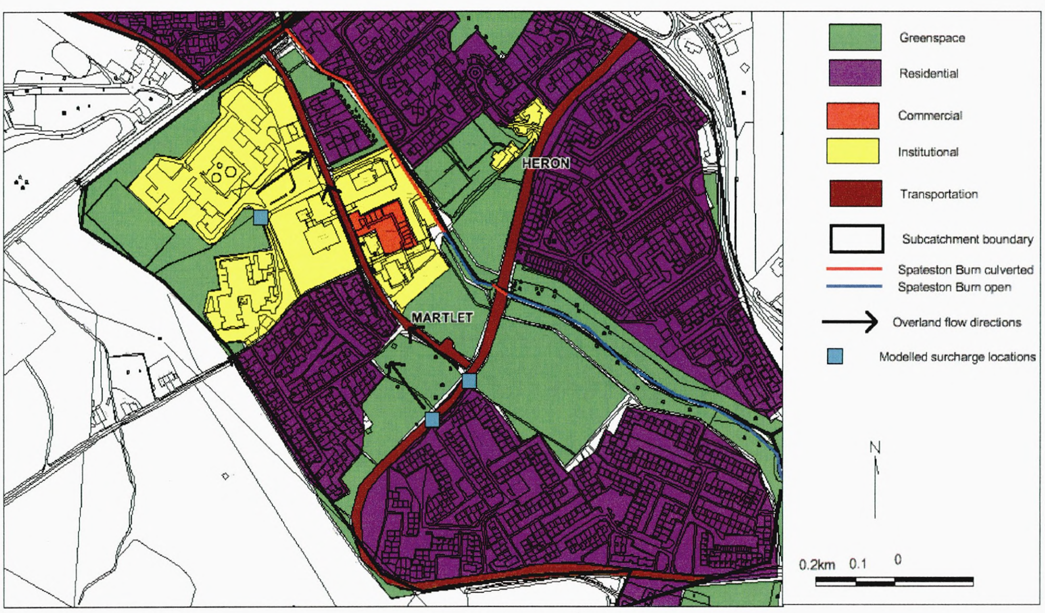


Figure 6- 6: Spatial planning and flooding in Martlet Street (arrows show overland flow routes)
(Map source: Renfrewshire Council)

Heron

Model simulations showed that surcharging of manholes occurred at several locations in the sub-catchment. Overland flow caused by surcharging would drain down towards amenity areas and finally into the watercourse as shown by Figure 6-7 which indicates surcharging locations (light blue spots) from some locations causing overland flow (The direction of the overland flow was judged using topographic data in Appendix C2, Figure 5).

Figure 6- 7: Spatial planning and flooding in Heron (arrows show overland flow routes)
(Map source: Renfrewshire Council)

Ettrick

In Ettrick, the simulations show that flooding would be generated at the lower end. The modelled surcharging locations are shown in Figure 6-8. There was surcharging in the system due to lack of capacity and flatter gradients (The topographical plan of the sub-catchment is shown in Appendix C2, Figure 6. The flooding would get further exacerbated due to the presence of a railway embankment downstream of the sub-catchment. As the culverted watercourse (Spateston Burn is culverted in most portion of this sub-catchment) is surcharged during 200 yr flooding event, there would be a lack of escape routes for the flood water generated in the surface water system.

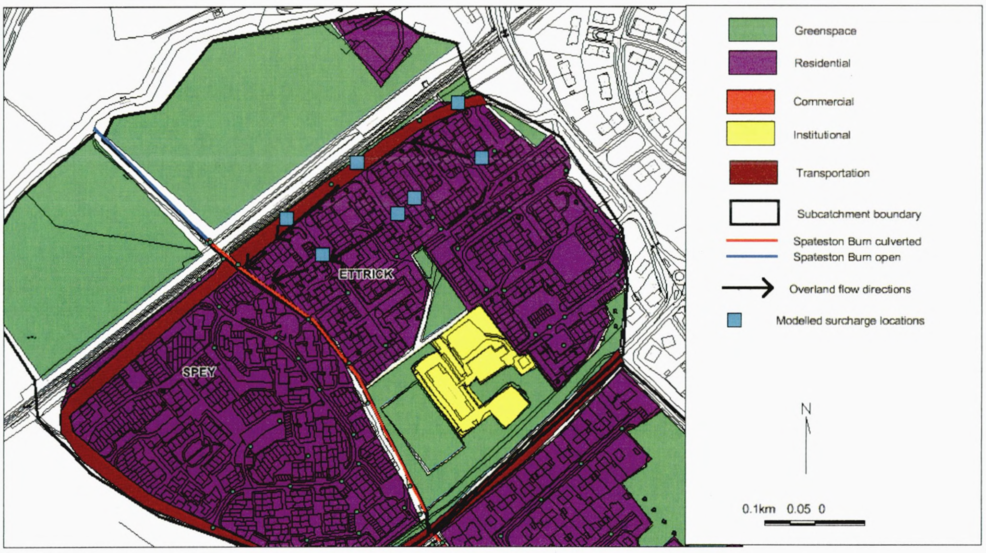


Figure 6- 8: Spatial planning and flooding in Ettrick (arrows show overland flow routes)

(Map source: Renfrewshire Council)

Step 2c: Assess vulnerability of areas from sewer flooding as well as overland flow

There is more risk of flooding in the lower reaches where Ettrick Street is located. This is evident from the modelling results of the sub-catchments. As Ettrick mainly comprises of high density residential areas, it is more vulnerable to flooding than Martlet Street, which contains a mix of water compatible green spaces as well as some residential areas. Flooding was likely to be caused in the parking areas of the secondary school in Martlet which could affect residents located near the Spateston Burn. In Heron, some of residential areas were more vulnerable to flooding as they were located in low lying areas closer to the watercourse. The relationship between modelled flooding and vulnerability of land uses is shown in Table 6-2.

Table 6- 2: Spatial sensitivity planning in Martlet Street and Ettrick Terrace

Sub-catchment	Modelled flooding using 200 yr event (m^3)	Current land use	Vulnerability	Remarks
Martlet	353	Green spaces	Water compatible	
		Residential and	More vulnerable	Risk of overland flow
		Institutional (Schools)	Less vulnerability	Potential risk of flooding in institutional areas and residential areas
Heron	275	Green spaces	Water compatible	
		Residential	More vulnerable	Risk of flooding through overland flow
		Commercial	Less vulnerability	
Ettrick	924	Residential and open spaces	More vulnerable	There is negligible green space and hence the whole sub-catchment is more vulnerable

Discussion to stage 2

The risk of flooding increased in the lower part of the catchment. However, the housing development density is also greater in Ettrick which lies in the lower portion of the catchment. This causes greater vulnerability to the housing areas in Ettrick. Furthermore, there are hardly any green space in the Ettrick sub-catchment unlike Martlet and Heron which causes worsening of flooding. This indicates the need for more even distribution of green spaces for the mitigation of flooding.

Although the model indicated surcharging in all the three sub-catchments, however the flooding would cause greater impact in Ettrick. This is due to the fact that Ettrick had flat gradient but Martlet and Heron had steep gradients which would enable the surcharged flow to drain down towards the watercourse or the sewer systems downstream. It is likely that due to the greater impact of flooding in Ettrick, the residents reported flooding whilst due to little impact in Martlet and Heron there were no reported historical flooding in these sub-catchments.

6.4 STAGE 3: GREEN SPACE ASSESSMENT

Step 3a Categorise green spaces

Spateston catchment is a partially developed suburban catchment with plenty of open spaces. The distribution of green spaces within the catchment is non-uniform. Most of the green spaces are present in the upstream locations while very little is available in the housing estates. Some of the amenity areas within the developments are non-usable for functional recreation due to steep slopes. The green spaces comprise 58 per cent of the total catchment area of 118 hectares. Most of the green spaces upstream of Martlet are farmland, while there are also some natural and semi-natural areas along the watercourse corridor. The farmland is private property and is not accessible to the residents. Other significant green spaces are present beside Spateston Road and at the junction of Spateston Burn and Black Cart River. A description of green space distribution of various types in the catchment is provided below:

-**Parks.** There is one park in a central location at the junction of Spateston Burn and Spateston Road. It has various facilities, such as a football pitch, children's play areas and walking paths. Part of the park beside the Spateston Burn is rich in biodiversity and wildlife.

-**Amenity Areas.** There are spread mainly in Martlet and Heron sub-catchments where they are located beside the open sections of Spateston Burn. There are also some amenity sites located inside the two schools in the catchment.

-**Playgrounds**. Playgrounds are mainly located in schools in the catchment. There are three local authority schools- two primary and one secondary. The schools have football pitches, grassed play areas, and other courts.

- **Natural and Semi-Natural Areas**. A significant portion of overall green spaces in the catchment falls under this category. These areas are primarily located near the Spateston Burn and beside the Black Cart River. A walking survey beside the watercourse showed that these areas were rich in biodiversity and wildlife.

- **Incidental Amenity Areas**. There are small pockets of incidental areas and play areas present in some of the sub-catchments. The overall plan of green spaces is shown in Figure 6-9.

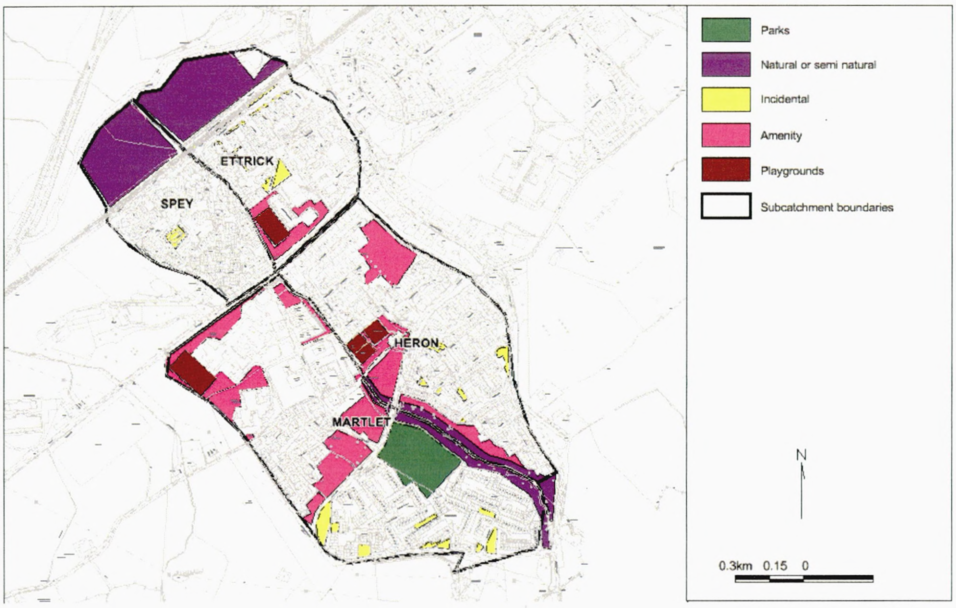


Figure 6- 9: Green space distribution in Spateston Burn Catchment
(Map source: Renfrewshire Council)

Step 3b: Analyse quantitative aspects of green space distribution

Quantitative analyses associated with the three selected sub-catchments are presented in this section.

Martlet

A total of 10.6 hectares of green space is present in Martlet. This includes school playgrounds, pitches, watercourse buffer areas, amenity areas, and recreational areas. The green spaces beside the road are mainly for visual amenity as they cannot be used for walking or playing areas due to the steep slopes. Green spaces in Martlet, adjacent to the watercourse, have been developed as walking areas, kick-about areas and children's play areas. About 3 hectares of green spaces at the edge of the sub-catchment and in the riparian areas of the watercourse comprise natural/semi-natural vegetation, while another 3 hectares are distributed throughout the developments as incidental green spaces. The remaining green spaces are in the form of playgrounds and amenity spaces. The layout of the green spaces in Martlet is presented in Appendix C3, Figure 1.

Heron

Although this sub-catchment is mainly residential, a total of 4.2 ha of green spaces are also present. Green spaces are mainly located beside the Spateston Burn. A buffer vegetation zone of varying widths is located throughout the open sections of the watercourse. Beyond the buffer vegetation informal amenity areas comprising 2.7 ha or 65 percent of amenity spaces are present which provide attractive green spaces with access to natural areas and the watercourse. Playgrounds and pitches comprising 6 percent of the total green spaces are also located within the amenity areas. The layout of the green spaces in Heron is presented in Appendix C3, Figure 6.

Ettrick

Natural green spaces are present in the sub-catchment adjacent to the Black Cart River. These are part of the flood plain and form 56% of the green space. Access is blocked by the railway line crossing the sub-catchment at Corseford Avenue. The area is mainly rich in biodiversity with lots of shrubs, trees and natural grassland. It is also part of the wider green network along the Black Cart River. The layout of the green spaces in Ettrick is presented in Appendix C3, Figure 11.

Overall distribution of various types of green spaces in the three subcatchments are summarised in Table 6-3.

Table 6- 3: Distribution of green spaces in sub-catchments (Area in Ha)

	Amenity	Playgrounds	Parks	Incidental	Natural/ Semi
Martlet	3.01	0.56	3.29	0.66	3.06
Heron	2.56	0.41	0	0.24	0.95
Ettrick	0	0	0	0.44	0.5

Step 3c Evaluate green space distribution in relation to water management potential

This section presents a comparative analysis to assess the opportunities for storm water management based on the position of green spaces within the catchment.

The distribution of green spaces around the watercourse in Martlet and Heron prevent flooding as they provide flood path. In these subcatchments housing is present after a buffer region or a floodplain of the watercourse while in the lower subcatchments the floodplains have been developed. Additionally, green spaces in Ettrick cannot be utilised for SUDS as due to the presence of the railway embankment. Existing green space patterns indicate that attenuation must be produced through upstream storage to mitigate flooding in the lower reaches.

Table 6-4 shows SUDS opportunities analysed in the catchment for four types of green spaces. The park in Martlet shows good opportunities for retrofitting SUDS and integrating it into other existing amenities in the park. The suitability of amenity areas is limited, as most of these areas had either steep slopes or were located upstream of residential or institutional areas. The housing estates in Heron and Martlet showed greater potential for planning SUDS as they had green spaces downstream of housing estates. Some institutional grounds in the catchment were located upstream of developments and thus were not suitable for the development of SUDS.

Table 6- 4: Green space distribution and SUDS potential

Green space location and opportunities	Martlet	Heron	Ettrick	Comparative evaluation
Parks	Large Park (1.7 ha)	No parks	No Parks	Maximum parkland in Martlet
Opportunities/ Constraints	Potential for basins and ponds	NA	NA	Most opportunities for integrated storm water management
Amenity areas	Several amenity areas	Open spaces present	No space	Most amenity areas in Martlet
Opportunities/ Constraints	Not suitable for SUDS due to steep slopes (1.76 ha) remaining area suitable (1.22 ha)	Amenity areas suitable for basins and ponds (1.98 ha) 0.6 ha not suitable	No opportunities	Most amenity spaces in Martlet unsuitable while ones in Heron are suitable for SUDS
Housing green spaces	Some green spaces within housing estates	Some green spaces within housing estates	No green spaces	Martlet has most green spaces within housing estates
Opportunities/ Constraints	Potential for swales at some sites (0.66 ha)	opportunities for swales	Potential for source control	The areas offer opportunities for multifunctional SUDS
Institutional grounds	Two playgrounds (0.7 ha)	One playground (0.4 ha)	No green spaces within housing estates	Playgrounds in Heron more suitable to due proximity to watercourse
Opportunities/ Constraints	Not feasible as they are located upstream of development area	Yes, potential for detention basins, ponds	No SUDS possible	Opportunity for pond

(Green space layout in the three subcatchments presented in Appendix C3)

Discussion to stage 3

The distribution of green spaces was related to the potential for development of SUDS in an area. For example, there is little SUDS potential in Ettrick whilst Martlet and Heron present ample opportunities. Larger green spaces such as parks and large amenity areas as present in Martlet and Heron provide opportunity for regional SUDS such as ponds and detention basins. Various SUDS options associated with green spaces are described in detail in Stage 4.

6.5 STAGE 4: PLANNING INTEGRATED SUSTAINABLE DRAINAGE OPTIONS

This section describes various SUDS options within the selected sub-catchments. Steps 4a and 4b deal with storm water and recreational aspects respectively of SUDS options. Plans for the various options as well as calculations of storage and treatment volumes of SUDS are presented in Appendix C4. Schemes were not proposed for Ettrick as GIS plans and site investigations showed lack of sufficient space for implementation of SUDS.

Step 4a Planning SUDS options - Storm water aspects

Four SUDS options are considered in Martlet and Heron sub-catchments. Site visits were undertaken to understand the constraints at the proposed SUDS sites. GIS and sewer network model data was also used to assess the feasibility of the options.

Martlet

This section discusses storm water issues associated with each option.

Option 1: One pond at Spateston Road

This option comprises an end of pipe pond in the parkland beside Spateston Road. This pond would have two inflows to drain Nightingale Place and Fulmar Place. The outflow would drain into the Spateston Burn. A contributing area of 6 hectares would drain this pond located at Spateston Road. Site conditions for the pond, including access for works and topography, were found to be favourable after site visits. The outflow from the pond will be linked to the surface water sewer joining the watercourse near the M8 Motorway. Schematic plan for the option is shown in Figure 6-10.

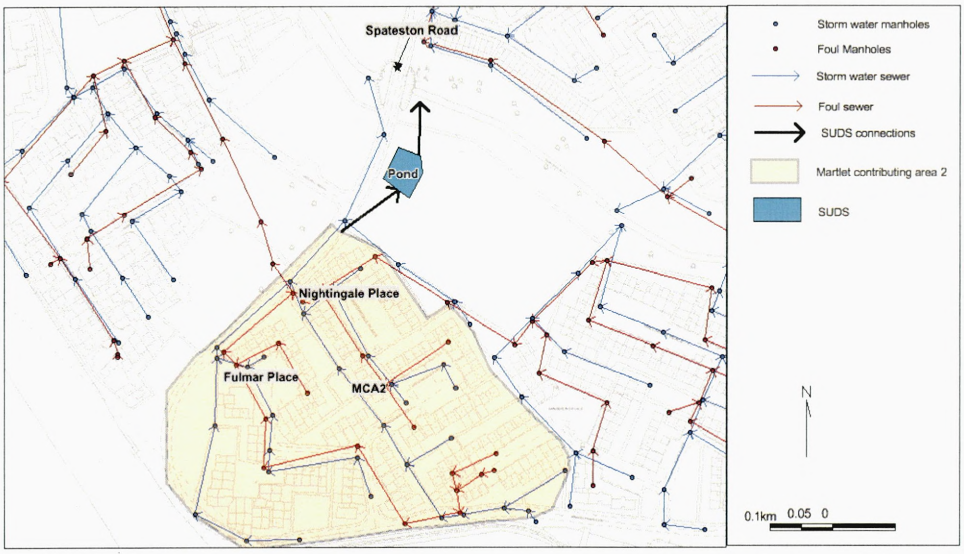


Figure 6- 10: Plan for Martlet SUDS Option 1 (Pond)
(Map source: Renfrewshire Council)

Option 2: A dry detention basin at Spateston Road

In this option, one detention basin is provided to intercept and attenuate the runoff from Nightingale Place and Martlet Place. Subsequently, the attenuated flow would join the watercourse. The locations of the basin and the contributing areas are shown in Figure 6-11. The proposed basin is located at the same site as the proposed pond from option 1; therefore the conditions for access and topography would be the same.

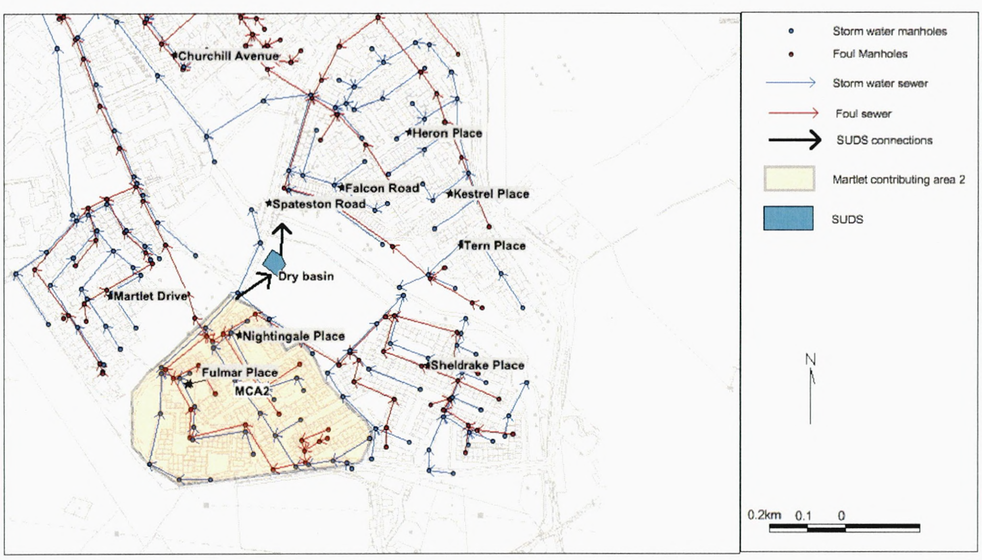


Figure 6- 11: Plan for Martlet SUDS Option 2 (Dry basin)
(Map source: Renfrewshire Council)

Option 3: Two wet detention basins at Spateston Road

Two wet detention basins are proposed as the third option. The basins are proposed at Nightingale Place and Sheldrake Place to receive runoff from the respective housing estates and then convey the outflow into the proposed basin near Spateston Burn, in the park area beside Spateston Road (refer to Figure 6-12). The hydraulic parameters of the basins are shown in Table 6-5, while the calculations are presented in Appendix C4. The total developed area of 57% would contribute to the attenuation volume, but there is no provision for long term storage volume in this scenario.

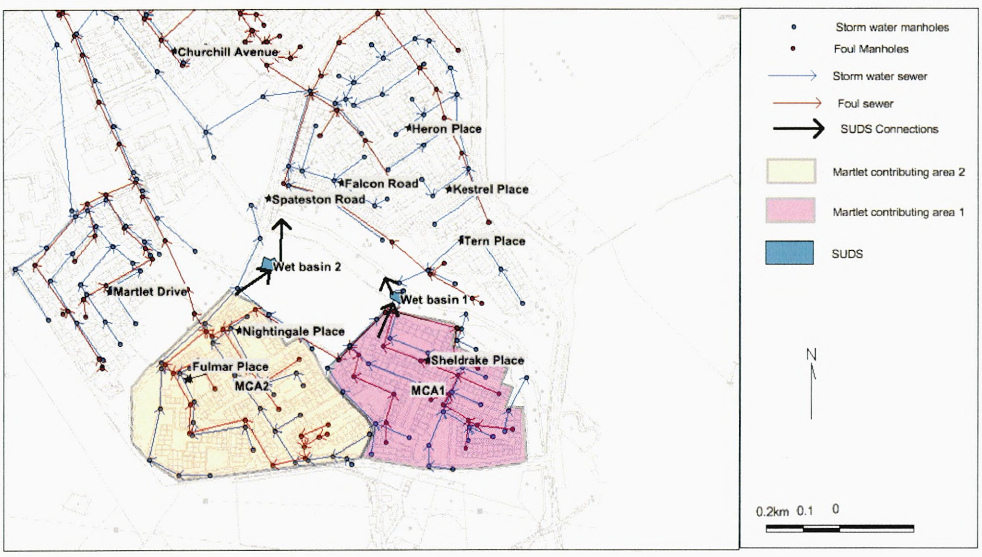


Figure 6- 12: Plan for Martlet SUDS Option 3 (Two wet basins)
(Map source: Renfrewshire Council)

Option 4: Two ponds: one at Spateston Road and another at Johnstone Secondary School, as well as two wet basins near Spateston Road.

These proposed ponds would provide attenuation volume for 85% of the sub-catchment. An area of 30% contributes to long term storage as per this option. The attenuated flow from the outlet could then join the surface water system associated with the watercourse. Schematic plan for the option is shown in Figure 6-13. The hydraulic parameters of the basins are shown in Table 6-5, while the calculations are presented in Appendix C4.

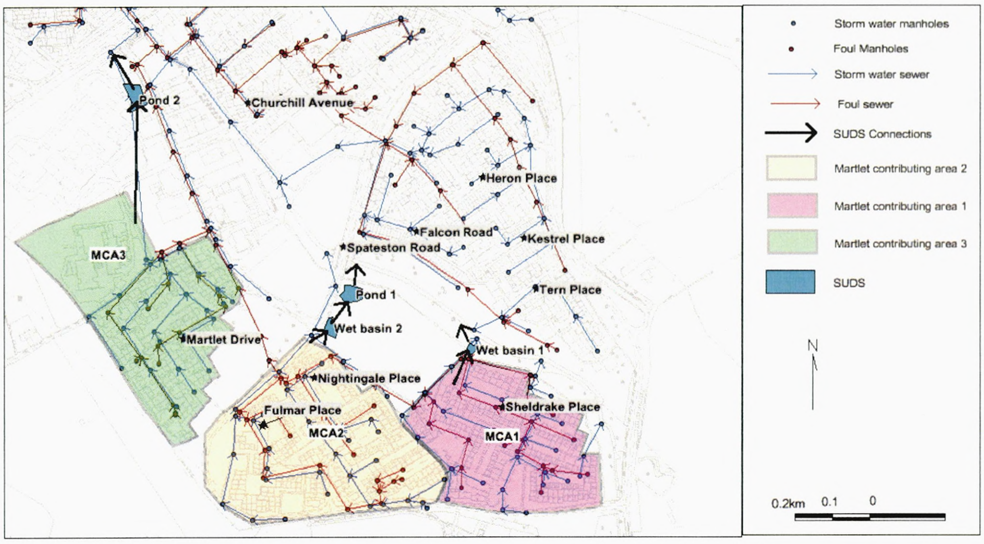


Figure 6- 13: Plan for Martlet SUDS Option 4 (Two ponds and two wet basins)
(Map source: Renfrewshire Council)

Summary

SUDS design factors associated with each option are summarised in Table 6-5. The calculations involved are shown in Appendix C4. The amount of contributing areas for each option is shown in Table 6-6. The variations in contributions were designed so that sensitivity of various SUDS options towards peak flow and flooding could be determined.

Table 6- 5: Hydraulic design parameters of proposed SUDS options

Option No.	Option description	Contributing areas	Attenuation volume	Treatment volume	SUDS volume
		(ha)	(m^3)	(m^3)	(m^3)
1	one pond	6	800	581	1962
2	one basin	6	578	581	1158
3	two basins	6	578	581	578
		3	315	317	315
4	two basins &	6	578	359	357
		3	315	486	483
	two ponds	8	222	845	2013
		6	923	669	2677

(Design parameters and calculations of alternative options in Appendix C4)

Table 6- 6: Proposed proportion of developments contributing to Attenuation and Long term volumes

	Proportion of developed area contributing to attenuation volume (%)	Proportion of developed contributing to long term volume (%)
Option 1	40	30
Option 2	40	15
Option 3	57	0
Option 4	90	70

Heron

Four options for SUDS were considered for the sub-catchment. The options comprise potential SUDS in the green spaces downstream of housing estates. The sites for SUDS were identified based on GIS data and site visits. SUDS design factors are summarised in Table 6-7, while Table 6-8 provides the proportion of developed areas contributing to attenuation and long term storage volumes.

Option 1: One pond at disused play area

A pond is proposed for development at a disused playing pitch near Churchill Avenue. This pond would receive inflows from several housing estates in the sub-catchment upstream of Spateston Road. The outflow from the pond would drain into the Spateston Burn.

The site of the proposed pond is accessible from Churchill Avenue. This site is flat as it was previously developed as a playing pitch and is, therefore, ideal for the development of a pond. Separate sewer drainage for the upstream housing estate could be easily linked to the pond as there is sufficient head for the flow. Further, as this site is located close to the watercourse, the outflow from the pond could be connected to the Spateston Burn. Schematic plan for the option is shown in Figure 6-14.

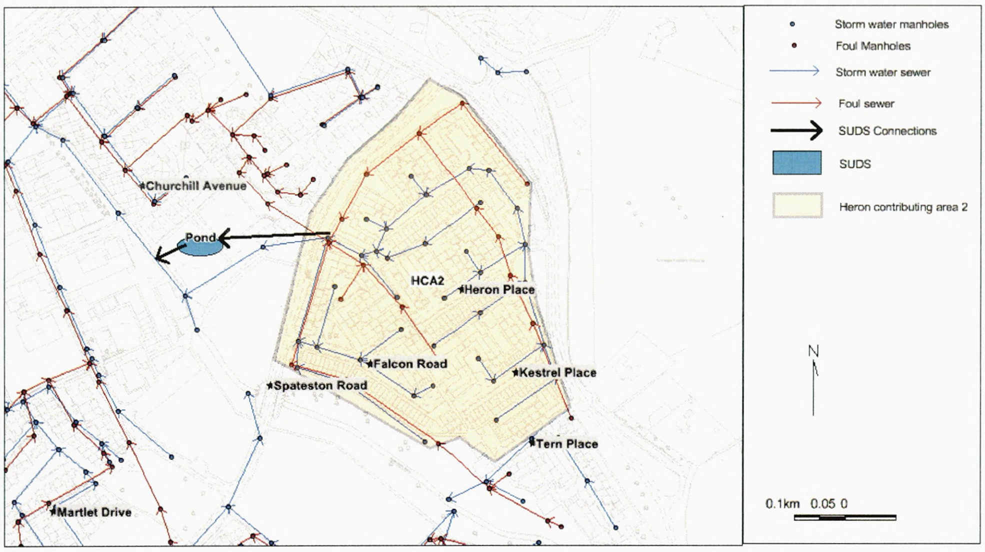


Figure 6- 14: Plan for Heron SUDS Option 1 (Pond)

(Map source: Renfrewshire Council)

Option 2: A dry detention basin at the Spateston Road

In this option, one detention basin is provided to intercept and attenuate the runoff from Falcon Road housing estates. Subsequently, the attenuated flow would join the watercourse. The locations of the basin and the contributing areas are shown in Figure 6-15. As the site of this basin would be the same as the proposed pond in option 1, it would have the same feasibility aspects associated with it.

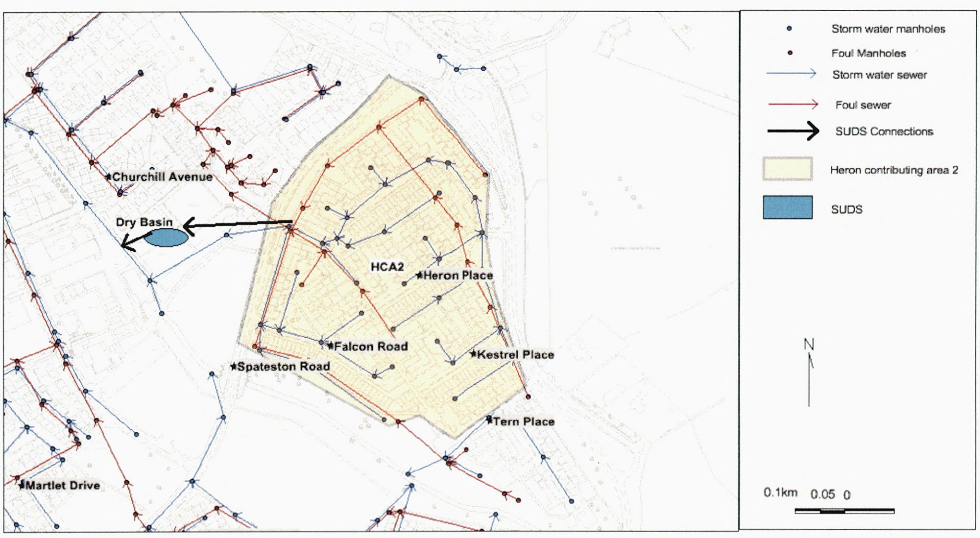


Figure 6- 15: Plan for Heron SUDS Option 2 (Dry basin)

(Map source: Renfrewshire Council)

Option 3: One pond and one upstream wet basin at Spateston Road

A pond and a wet basin are proposed as the third option. The basin is proposed beside the Spateston Burn at Tem Place and would receive runoff from the upstream housing estates and then convey the outflow into Spateston Burn. Contributing area for the pond would be the same as in option 1. However, this option comprises a second site for additional attenuation. The proposed basin would attenuate flows from a development site of 1 ha. The hydraulic parameters of the two SUDS were calculated (Appendix C 4) and a summary of the SUDS design parameters is provided in Table 6-6. The schematic plan for the SUDS option is presented in Figure 6-16.

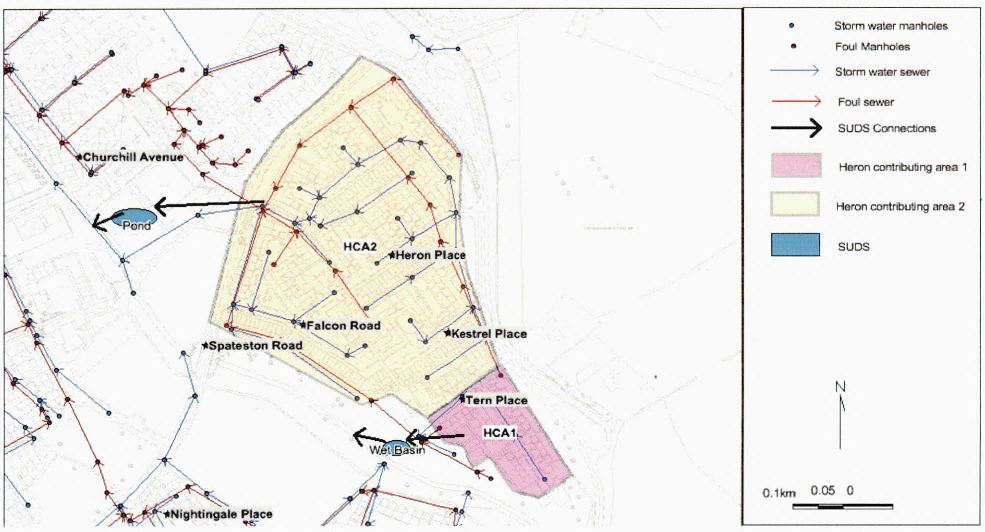


Figure 6- 16: Plan for Heron SUDS Option 3 (Pond and a wet basin)

(Map source: Renfrewshire Council)

Option 4: Two wet Basins: One basin at Tern Place and another at Churchill Avenue

This option comprises of two wet basins at the same sites as in option 3. The basin near Churchill Avenue would be larger as it will provide attenuation for 6 ha of upstream catchment area while the other basin will provide attenuation for only 1 ha of catchment area. There will also be a long term attenuation area for extreme events for the basin at Churchill Avenue. The outline plan for the scheme is presented in Figure 6-17.

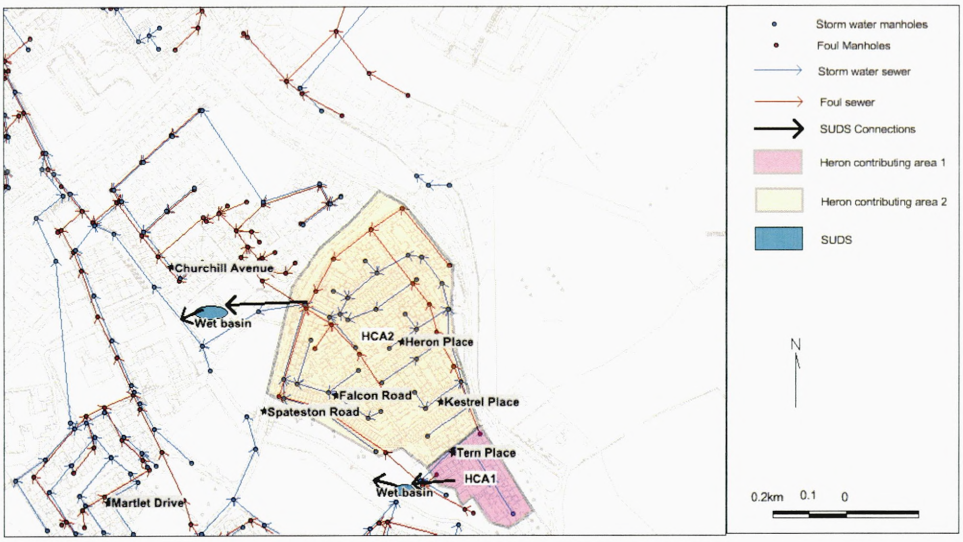


Figure 6- 17: Plan for Heron SUDS Option 4 ((Two wet basins)

(Map source: Renfrewshire Council)

Summary

SUDS design factors associated with each option are summarised in Table 6-7. The calculations involved in SUDS design are shown in Appendix C4. The amount of contributing areas for each option is shown in Table 6-8.

Table 6- 7: Hydraulic design parameters of proposed SUDS for various options

Option No.	Option description	Contributing areas	Attenuation volume	Treatment volume	SUDS volume
		(ha)	(m^3)	(m^3)	(m^3)
1	one pond	6	1128	633	2394
2	one basin	6	795	633	1428
3	one pond	1	114	91	205
	one basin	6	1128	633	2394
4	two basins	1	114	91	205
		6	795	633	1428

(Design parameters and calculations of alternative options in Appendix C4)

Table 6- 8: Proposed proportion of developments contributing to Attenuation and Long term volumes

	Proportion of developed contributing to attenuation volume (%)	Proportion of developed contributing to long term volume (%)
Option 1	50	20
Option 2	50	50
Option 3	58	0
Option 4	58	30

Ettrick

Adequate open spaces at appropriate locations do not exist in this sub-catchment for planning of retrofit SUDS. There are some green spaces on the school site, but this site lies in the upstream part of the sub-catchment while the housing estates in the subcatchments are draining downstream towards the Black Cart and so the school site cannot be used for SUDS options (refer to Appendix C1 Figure 18). There is also some green space near the Black Cart, but it cannot the accessed due to the railway embankment.

Step 4b Planning SUDS options - Recreational aspects

Recreational potential for the various options in the two sub-catchments were analysed and presented in this section. Three parameters were used to assess the potential for recreation, i.e. area of water visibility, diversity and size of potential vegetation, and footpaths in the vicinity of retrofit SUDS.

Martlet

Option 1: One pond at Spateston Road

The proposed pond at Spateston Road could provide a high amenity value to the site. This location also has good connectivity with houses, schools, green spaces and could be useful for multiple-uses, such as walking, sitting, picnic areas and fishing. The site would provide good passive surveillance for safety of users.

This pond would enhance the ecological potential of the sites. Multiple vegetation categories, such as trees, shrubs, grasses and aquatic plants, could be promoted at this site. It would also attract a variety of wildlife, including fish, amphibians, reptiles, birds and mammals (Heal 2010).

Option 2: A dry detention basin at Spateston Road

The dry detention basin at the proposed site would provide amenity benefits. However, due to lack of visible water and variety in vegetation there would be less amenity value than the proposed pond in option 1. The site would be grassed and need regular trimming. However, the basin could be developed for multiple uses, and facilities for walking and seating could also be developed at the site. The safety risk perception associated with the presence of permanent pool of water will not be there as it is a dry basin.

Option 3: Two wet detention basins at Spateston Road

There would be several recreational benefits due to the proposed wet basins. The basins would have a wide variety of vegetation. The basins will also be well connected to adjoining housing areas with existing footpaths and would have good passive surveillance due to presence of roads and nearby housing estate. Their potential for multiple uses would however be limited, although the basin could be designed as a kick-about area.

Option 4: Two ponds, one at Spateston Road and another at the secondary school

Two ponds are proposed as part of this proposal. Whilst one pond would be located on public land, the other would be located in the school area. The pond in the school would be designed as a shallow pond so as not to cause a safety hazard to the children. This pond could also be useful for educational purposes for the schoolchildren. Ecological features of the pond would be similar to the other proposals. It would offer multi-functionality and would connect to the playing areas nearby.

Heron

Option 1: One pond at disused play area

This site is located near commercial and residential areas. Therefore, it will enhance the vitality of the area. The footpaths linking the site could become more popular for pedestrians once the pond is fully established. The visibility of water will further add value to the location. However, the presence of a permanent pool of water is also likely to involve a safety risk perception among the residents in the area and appropriate design and signage could reduce the perception.

Option 2: A dry detention basin at Spateston Road

The proposed detention basin could have multiple uses as it can be used as play area in addition to providing storage for attenuation and long term volumes. However, the amenity value, aesthetics will be lower in comparison to the pond. The safety risk perception of the basin will be lower than the pond due to a lack of permanent pool of water. It will be out of use only during periods of heavy rainfall. The site has a good connectivity with other areas and presence of housing nearby would ensure good passive surveillance for the site.

Option 3: One pond and one upstream wet basin at Spateston Road

This option comprising SUDS at two sites would provide recreational functions. The pond would have the same recreational aspects as option 1. The pond will have high aesthetic value, but would also have an associated perception of safety hazard. The safety risk could be minimised by appropriate design and barrier plantations as recommended by Woods-Ballard *et al.* (2007). The pond site could be provided with seats and footpaths. The green space in the vicinity of the proposed basin could serve as a kick-about area. Therefore, this option would provide multiple recreational benefits at both sites.

Option 4: Two wet Basins: One basin at Tern Place and another at Churchill Avenue

The two wet basins could have multiple functions. They would provide informal recreational areas with a variety of vegetation. As these sites are closer to the watercourse they will have an important role in promoting biodiversity in the sub-catchments. Existing facilities such as footpaths would become more attractive because of potential vegetation and wildlife promoted in the basins. The site at Churchill Avenue is located centrally with housing estates all around and would thus provide passive surveillance as well.

Discussion to stage 4

There are various possibilities for planning of SUDS within the two sub-catchments. The options present in parks provide opportunities for linking with park activities while SUDS options in residential areas provide opportunities for local recreation. This approach of SUDS planning which entails linking it to the surrounding context would also fulfil the policy requirements set out in PPS 17 and SPP.

6.6 STAGE 5: HYDRAULIC EVALUATION OF SUDS OPTIONS

The effect of retrofit SUDS was modelled for two sub-catchments: Martlet and Heron as presented here. The hydraulic model provided by consultants (and used to assess existing flooding stage 2 as discussed in stage 2) was modified for use in stage 5 as discussed in step 5a. Data used for running the model is provided in step 5b while 5c illustrates the reduction of 30 yr peak flows in comparison to existing 30 yr peak flows of several SUDS options and optimum scenarios. Hydrographs representing reductions of peak flows for 10, 30 and 200 yrs are presented in Appendix C5.

Step 5a Model modifications to represent SUDS options

The hydraulic model used in stage 2 was modified to represent the effect of retrofit SUDS. Storage and treatment volumes as determined from section 6-5 were used to indicate the impact of SUDS. Separate versions were developed for each option of SUDS to analyse the benefits of providing attenuation storage. Optimum scenarios were also created to represent situations of providing SUDS in both sub-catchments.

Martlet

Four model variations were created to represent the conceptual solutions identified in stage4. The outflows from the SUDS were restricted to green field levels (Table 6-9) using orifices for each SUDS option. Overview weirs leading to long term storage areas were also provided for all SUDS options. Outflow from the LTV was throttled at a rate of 2l/s/ha with total values as shown in Table 6-9.

Table 6- 9: Calculations for individual SUDS Options in Martlet

Model variations	1	2	3		4			
	Pond	Basin	Basin 1	Basin 2	Basin 1	Basin 2	Pond1	Pond2
SUDS discharges (l/s)	40.3	40.3	40.3	22	40.3	22	58.6	46.5
LTV discharge (l/s)	9	4.5	0	0	6	3	0	12

Heron

Four options for SUDS were considered for the sub-catchment. Similar outflow and overflow arrangements were provided as in the case of Martlet. SUDS and LTV discharges for each model option are shown in Table 6-10.

Table 6- 10: Calculations for individual SUDS Options in Heron

Model variations	1	2	3		4	
	Pond	Basin	Basin	Pond	Basin1	Basin2
SUDS discharges (l/s)	44	44	6.3	44	6.3	44
LTV discharge (l/s)	4.7	15	0	0	0	9

Step 5b Running simulations

The modified model is run against 10, 30 and 200 years design storms of various return periods. The critical duration return period is established after examining the flooding from various events. Peak flows will be determined for 10, 30 and 200 yrs critical events.

Step 5c Comparisons of peak flow in existing and SUDS options

The results were studied to assess the possible release in sewer capacity (enhancement of capacity due to disconnection of runoff from the sewer system) as well as a decrease of flooding at the catchment scale. A comparison of existing peak flows with that from various SUDS scenarios is presented in Figure 6-18 and Figure 6-19 for 30 yr return period events.

Martlet

The comparative hydrographs show that Option 4 produced lowest peaks. This is due to maximum contribution of impermeable area to SUDS for this option (90 % of the total impermeable area) while contribution of impermeable areas in other options (40 to 57 % of the total impermeable area) are much lower. This is shown in Table 7 in Appendix C4.

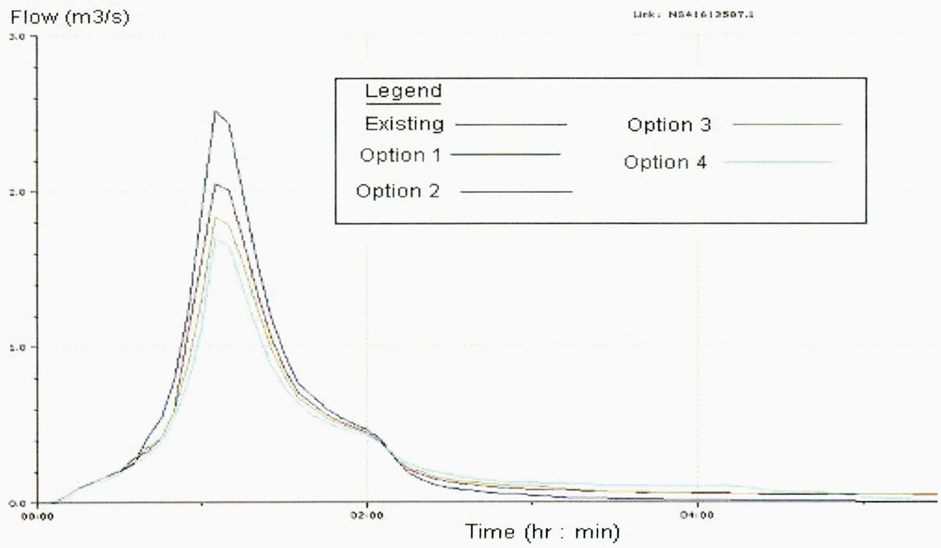


Figure 6- 18: Peak flow from various SUDS options in Martlet (Plans for alternative options in Appendix C5)

Heron

Option 1 hydrograph is similar to that of Option 2 and similarly options 3 and option 4 had similar profiles. The results indicated low sensitivity of the hydrographs to the type of SUDS options used. However, significant changes in contributing areas (eg. Option 1 and Option 4) did lead to appreciable changes in the flow regime hydrographs (Refer to Figure 6-20). The 200 yr hydrographs (Refer to Figure 6 in Appendix B5) indicated lower sensitivity to the changes in long term volumes.

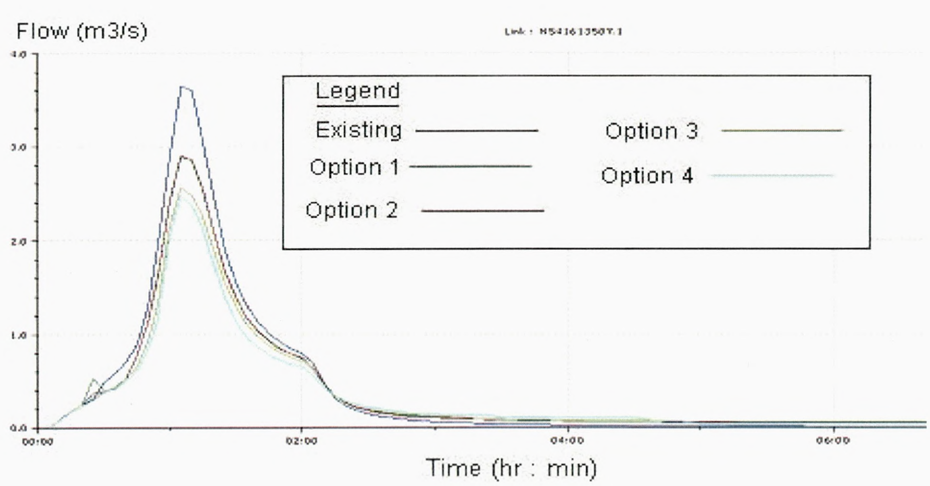


Figure 6- 19: Peak flow from various SUDS options in Heron (Plans for alternative options in Appendix C5)

Discussion to stage 5

SUDS options developed by disconnecting larger contributing areas generated more flood attenuation. For example, option 4 in Martlet provided maximum flood attenuation as significant portion of the impervious areas is proposed to be disconnected. In both sub-catchments the hydrographs showed lower sensitivity to the type of SUDS option as well as the long term return period.

6.7 STAGE 6: INTEGRATED EVALUATION OF SUDS OPTIONS

The following section describes the steps for integrated evaluation of SUDS. Step 6a describes the integrated scoring matrix to compare various schemes. The preferred option, as determined from scoring, is described in 6b, where stakeholder response is also analysed.

Step 6a Scoring of SUDS options

The various options, identified in stage 4, for planning of retrofit SUDS are scored using the evaluation matrix developed in Chapter 4. This matrix comprises recreation and storm water parameters for integrated evaluation of the alternatives. The scores associated with each SUDS option for the sub-catchments of Martlet and Heron is displayed in Table 6-9 and Table 6-10 respectively, while the calculations and the relevant attributes of each indicator considered for scoring are provided in Appendix C6.

Table 6- 11: Application of integrated scoring matrix for retrofit SUDS options in Martlet

(Calculations for obtaining the scores in Appendix C6)

Option No.	1	2	3	4
Indicators				
Access	1.2	1.2	1.2	1.8
Water visibility	2.1	0.7	1.4	2.1
Aesthetics	2.1	0.7	1.4	2.1
passive security	1.2	1.2	1.8	1.8
Multi-purpose	2.4	2.4	2.4	2.4
Safety	0.8	2.4	1.6	0.8
Ownership	2.1	2.1	2.1	2.1
Flood return period	5.1	3.4	3.4	5.1
Attenuation volume	3.2	3.2	3.2	4.8
Long term storage	1.6	1.6	0	4.8
total score	21.8	18.9	18.5	27.8

Preferred solution

Table 6- 12: Application of integrated scoring matrix for retrofit SUDS options in Heron

(Calculations for obtaining the scores in Appendix C6)

Option No.	1	2	3	4
Indicators				
Access	1.8	1.8	1.8	1.8
Water visibility	2.1	0.7	2.1	1.4
Aesthetics	2.1	0.7	2.1	1.4
passive security	1.8	1.8	1.8	1.8
Multi-purpose	1.6	0.8	1.6	1.6
Safety	0.8	2.4	0.8	1.6
Ownership	2.1	2.1	2.1	2.1
Flood return period	5.1	3.4	5.1	3.4
Attenuation volume	3.2	3.2	3.2	3.2
Long term storage	1.6	3.2	0	1.6
total score	26.6	22.7	20.5	21.1

Preferred solution

Step 6b Final proposed SUDS Schemes

Martlet

The preferred option for Martlet is Option 4. This option comprises of two pond and two wet basins. This option provides attenuation to the maximum amount of impermeable area in the sub-catchment in addition to providing high recreational attributes. Option 1 was allotted high recreational scores due to several attributes associated with high amenity value but received low scores due to lower impermeable area disconnected. Option 2 comprising of a dry detention basin received lower scores due to lower recreational scores. Similarly Option 3 comprising of two detention basin was allotted a lower score due to its lower recreational scores in comparison to the two pond options of 1 and 4.

The proposed solution at Martlet comprises two basins and two ponds (option 4 in Table 6-11). One pond would receive runoff from Nightingale and Fulmar Places, while another pond will be located at the secondary school. The basins would be situated near Sheldrake Place and Spateston Road. The existing separate sewers could be used to drain these estates into their respective SUDS (refer to Figure 6-20).

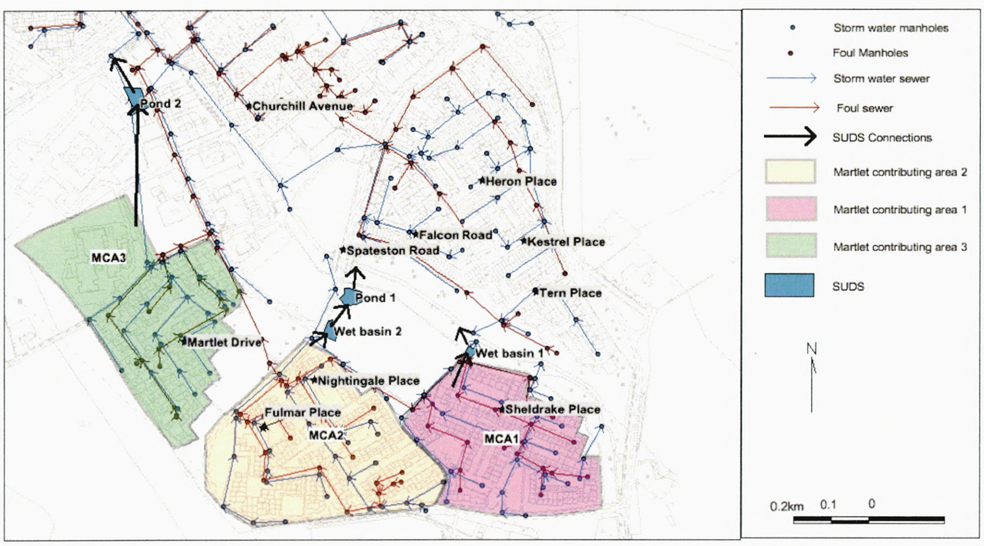


Figure 6- 20: Plan of the preferred option in Martlet
(Map source: Renfrewshire Council)

The proposed basins and ponds would provide greater reduction to peak flows as seen from hydraulic assessment in stage 5. Although, the amenity and ecological values provided are similar to option 1, this option will provide greater areas for recreation than other options.

The proposed basins would enhance the amenity value of the site. Currently, the site has grassed areas with no other vegetation. The planting of other vegetation, such as a variety of herbs, shrubs and trees, would make the site more aesthetically pleasing and encourage more use of the park. Sitting and meeting places could be provided for various age groups. The vegetated areas could provide attractive and exciting play areas for informal play.

Provision of a pond at Spateston Road and at the secondary school would help make them focal points in the area. If provided with sitting and meeting places for interaction it would encourage development of community spirit. It would be visible from Spateston Road as well as from the housing estate at Nightingale Place and would, therefore, have good passive surveillance. The presence of other play equipment in the park would add further vitality to the site (refer to Figure 6-21).

Figure 6- 21: Location of proposed pond beside Spateston Road (shown by arrow)
(Source: Google Street view)

The proposed ponds would enhance the biodiversity of the sub-catchment. Currently, there is rich biodiversity in the Spateston Burn watercourse corridor. This pond would encourage the growth of wetland associated species, such as water vole, frogs and dragonflies. It would support a variety of aquatic, marshland and terrestrial plants.

Heron

Option 1 was selected as the preferred option out of the four assessed options. It was allocated high scores for both recreation and storm water management indicators.

Option 2 had high storm water scores, while Option 4 was given lowest score due to average recreation scores and low storm water scores (Table 6-12). The relevant attributes of each indicator considered for scoring are provided in Appendix C6.

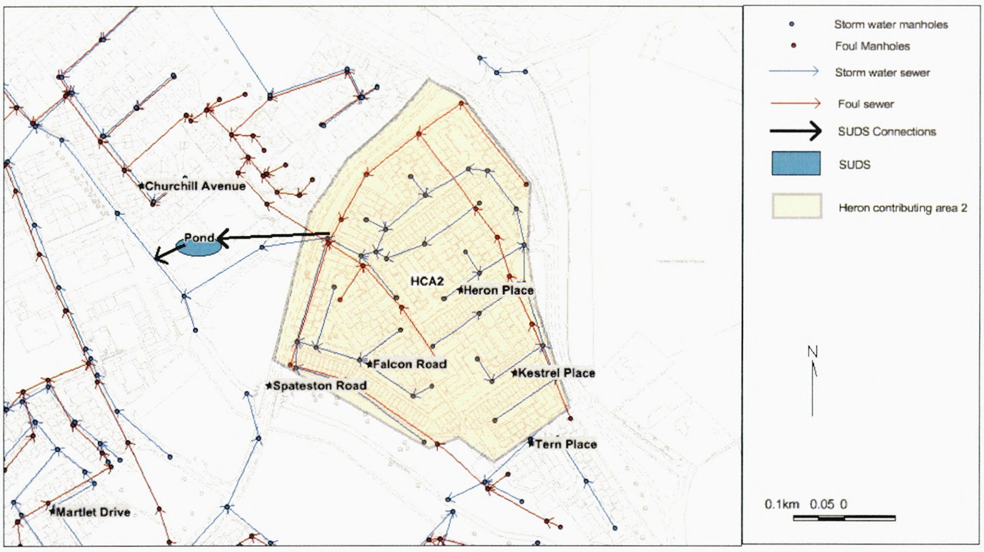


Figure 6- 22: Plan of the preferred option in Heron
(Map source: Renfrewshire Council)

The proposed option comprises of a pond on a disused playing pitch. The proposed pond could become a valuable amenity asset for the housing estates surrounding Spateston Road and Churchill Avenue (refer to Figure 6-22). The place would become more appealing to the residents due to the growth of more vegetation and wildlife. The pedestrian path nearby could become an attractive walking route for school children going to the nearby school at Halhill Road (refer to Figure 6-23).

Biodiversity would be generated at the pond site as a result of the scheme. Native vegetation, comprising grasses, shrubs and trees, should be planted to develop various habitats for wildlife species. Some species, like swans and ducks, could be introduced to add vitality to the site, as with some other ponds in Scotland, such as Ardler pond in Dundee (British Home Awards 2007).

Other options could also provide several benefits, however the overall benefits would be lower than the proposed option. The dry basin of option 2 could be developed into an amenity and storage area. Similarly, option 4 comprising of wet basins would also provide amenity benefits. However, the perceived recreation and amenity benefits of a pond will be greater than non-pond options.

Figure 6- 23: Location of proposed Pond (shown by arrow)
(Source: Google Street view)

Discussion to stage 6

Indicator values in Table 6-11 and Table 6-12 show that a variety of SUDS schemes were considered so that the sensitivity of the scoring system could be evaluated. Among the recreational indicators, access, multi-purpose and ownership had two variations while the other indicators had three alternatives for Martlet (Refer to table 6-11). In Heron, water visibility, aesthetics, and safety had three alternatives while the other recreational indicators (refer to Table 6-12). Among the storm water indicators for Martlet the schemes show two variations for two attributes (flood return period and attenuation volume) and three variations for the third parameter (refer to Table 6-11). In Heron there were two alternatives considered for return period and three for long term volumes, but there were no variations used for attenuation volume.

The option selected for Martlet had higher storm water scores than other options. Similarly, in Heron sub-catchment option 1, which had higher storm water scores, was selected as the preferred option. Further, as each storm water indicator had a higher normalised weighting than recreational indicators, options with higher storm water indicator scores were more likely to become the preferred options.

Sensitivity assessment of the recreational and storm water indicators is carried out in section 7-3. Total recreational and storm water scores have been compared for existing scenarios as well as the potential scenario of increasing and decreasing the scores by10% and 20%. The development of several options was itself carried out to study the sensitivity of all indicators. Section 7-5 discusses the sensitivity of existing indicators both recreational and storm water towards maximising the total scores in the four options of the two sub-catchments studied.

The scoring tool provided a method to evaluate the various parameters for each option. This method also provides an opportunity for balancing the amenity requirements of urban planning to the needs of storm water management. This is in contrast to the previous SUDS planning approach where evaluation of recreational criteria was not adequately defined and hence often resulted in SUDS with little aesthetic or recreational value as noted by Debo and Reese (2003).

6.8 DISCUSSION

The catchment showed a good overall potential for integrated planning of storm water management. While Martlet and Heron, with a significant amount of open spaces, provided good opportunities for retrofitting SUDS within the sub-catchments, there were no opportunities for the same in Ettrick. Site analysis also showed that there could be recreational and associated biodiversity benefits from these schemes.

A lower proportion of green spaces in the lower reach of the catchment caused greater risk and vulnerability to flooding. In Ettrick, there are negligible green spaces, whilst in Martlet and Heron, where the risk of flooding is lower, there are substantial green spaces (described in section 6.3). Therefore, the distribution of green spaces is not water compatible. Planning for future regeneration, therefore, should focus on creating green spaces within Ettrick in order to further reduce the risk of flooding.

Assessment of green spaces (discussed in section 6.4) in the catchment shows various possibilities for integrating SUDS and recreational opportunities. The evaluation matrix shown in step 3d of section 6.4 also showed that some green spaces were more useful for planning retrofit SUDS than others. The matrix showed the variation in SUDS planning opportunities based on distribution of green spaces as well as quantity of green spaces. For example, Martlet with green spaces adjacent to the watercourse showed maximum opportunities for integrated SUDS sites and green space planning; there was little opportunity for SUDS sites in Ettrick. There were some green spaces in Ettrick, it was obstructed by a railway embankment and there was no green space adjacent to the watercourse.

Planning of SUDS options in section 6.5 showed they had different recreational and storm water management attributes considered at design stage. For example, in Martlet option 1, the pond was conceived as mainly for multi-functional benefits with paths for walking, seating areas, and meeting areas, however in option 2, the detention basin was conceived for the singular function of storm water management.

Results from the hydraulic model analysis (described in section 6.6) showed a variation in peak flow reductions according to the amount of storage provided and the return period mitigation. This reduction of peaks was evident for options for both the sub-catchments of Martlet and Heron as shown in Figure 6-18 and Figure 6.19.

Analysis in section 6.7 indicated that the evaluation tool discussed in chapter 4 showed potential for evaluating various SUDS options in order to arrive at a more holistically preferred SUDS option. This was illustrated in Table 6-11 and Table 6-12, which show that the final score for each SUDS option was sensitive to the various recreational and storm water management indicator scores. The final score was a trade-off between recreation and storm water management.

The conceptual framework and integrated evaluation tool was also useful in analysing and evaluating potential SUDS options in chapter 5. A comparison of the two studies is presented in chapter 7 (section 7.2) to discuss the similarities and differences in the two case studies. The implications of the results from chapter 5 and chapter 6 are discussed in chapter 7.

7 EVALUATION/ DISCUSSIONS

7.1 INTRODUCTION

In this chapter, a discussion and interpretation of the results are presented. Interpretation of the results, obtained from the case study investigations in the two catchments discussed in Chapters 5 and 6, is presented in section 7.2. The interpretation is based on the research issues identified in Chapter 2. Section 7.3 assesses the integrated planning framework that follows on from the results of the case studies and their interpretation. The implications of this research for green space and storm water planning are discussed in sections 7.4 and 7.5 respectively. Potential applications of the research in relation to existing planning systems are described in section 7.6. The benefits of the proposed methodology are enumerated in section 7.7 and these limitations are discussed in section 7.8.

7.2 DISCUSSION ON THE COMPARATIVE STUDIES

The two case study areas have similarities that allow for comparison of the results. In particular, both catchments had flooding in the lower reaches of the watercourse.

Identical methodologies were followed in both catchments although the patterns of development and drainage were different. In the Light Burn catchment, the whole catchment was developed urban area, while in Skerryvore, the upper portion of the catchment was undeveloped and the middle and lower portions were built up. This indicates that similar approaches of the proposed integrated framework (chapter 3) can be adopted if similar problems exist in a catchment irrespective of localised patterns of development.

The distribution of land use in addition to catchment characteristics was an important consideration for an integrated approach to SUDS planning (discussed in sections 5.2 and 6.2). A higher potential for SUDS was demonstrated in sub-catchments which had green spaces downstream of housing estates such as Skerryvore and Martlet (discussed in section 5.5 and 6.5).

Analyses of flooding (section 5.3 and section 6.3) and land use distribution (section 5.2 and section 6.2) showed similar patterns of flooding. The studies in both catchments showed that whilst flooding occurs in the lower reaches due to lack of buffer areas surrounding watercourses, upstream attenuation was needed to reduce flooding in such areas. The reduction of flooding by providing attenuation in upstream areas was demonstrated by reduced flow hydrographs in both catchments (Refer to Appendix B5 and C5). This supports the conventional wisdom that catchment approach is favourable for flood management.

Green space assessments in both catchments showed several sites suitable for SUDS as discussed in sections 5.4 and 6.4. Public parks in both Skerryvore and Martlet, catchments formed potential SUDS sites as they are located downstream of housing estates. Amenity and green spaces within housing areas provided sites for detention basins in both sub-catchments as shown in Garthamloch in the Light Burn catchment and Martlet and Heron in the Spateston Burn sub-catchment (discussed in sections 5.5 and . section 6.5). Highly developed areas such as Cardowan and Ettrick showed lack of potential for SUDS which indicates the desirability of more evenly distributed green space distribution taking into account not only access needs for residents but also the need for SUDS.

The SUDS design options in both the catchments (discussed in section 5.5 and section 6.5) included a range of SUDS such as ponds wet and dry detention basins. All five options in Skerryvore and three out of the four options in Martlet were proposed in parks. The indicators identified in chapter 4 were found to be applicable in both areas and the studies showed the potential for integrated conceptual planning using these indicators.

Results from the hydraulic model analysis described in section 5.6 and section 6.6 showed a variation in peak flow reductions according to the amount of storage provided and the return period mitigation. The peak flow was reduced for SUDS options in both catchments but the sensitivity of the peak flows to the variation of storm water indicators was more pronounced in the Spateston catchment. This reduction of peaks was evident for options for both the sub-catchments of Martlet and

Heron as shown in Figure 5-20 and Figure 6-20, while the differentiation is less in the Light Burn catchment as indicated in Figure 5-19 and Figure 5-20. The hydraulic analysis showed the potential of the storm water indicators in both the study catchments.

The application of the evaluation tool in section 5.7 and section 6.7 indicated the potential for assessment of a range of SUDS options having different recreational and storm water attributes. Although wet basins generally were allotted higher scores than the dry basins due to their higher aesthetic appeal and higher potential for multi-functional use, the storm water scores for dry and wet basins were similar since the return period was the same (10 yrs). All SUDS proposals in parks had potential for multifunctional use as seen from high scores in Skerryvore and Marlet. However, for the SUDS in other subcatchments such as Garthamloch (section 5.7) and Heron (section 6.7), multi-functional planning was not inherent in the existing spatial design due to lack of multiple recreational activities near the SUDS sites although the SUDS devices had the potential to provide some multi-functional activities.

7.3 COMPARISON OF RECREATIONAL AND STORM WATER SCORE EVALUATION

The recreational scores of the SUDS options were compared against the storm water scores to assess their relationships to the various indicators. The scores for recreation and storm water determined in sections 5-7 and 6-7 were used for sensitivity assessment. This section considers an assessment of changes in the parameters by ±10 % and ± 20% for both recreation and storm water scores denoted by RS and SS respectively.

Light Burn catchment

The recreational scores of options 1 to 4 were higher than the respective storm water scores. However, the storm water score of the fifth option was higher than all recreational scores as shown in Figure 7-1. The recreational score of option 3 is the highest while the storm water score of option 5 is the highest. If the recreational score of option 3 is increased by 20% then the recreational score becomes equal to existing storm water management score. Lowering of the recreational scoring of options 1 to 4 by up to 20% brought them to a similar level as the storm water scores as shown in Figure 7-1.

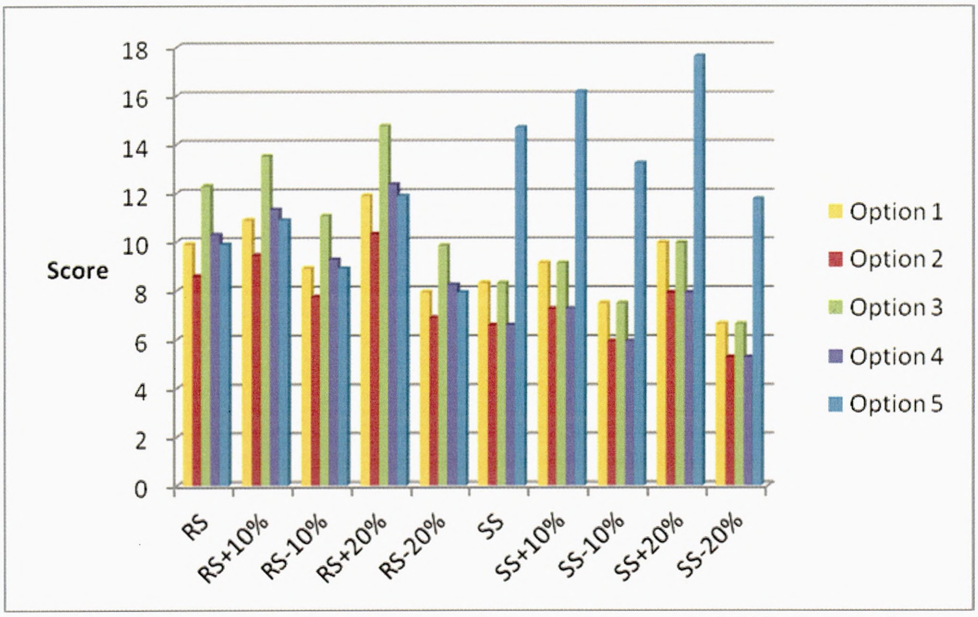


Figure 7- 1: Comparison of recreation and storm water scores in Garthamloch

For Skerryvore, SS for option 1 was higher than RS for all options. However, RS was higher for options 3, 4 and 5 while RS and SS were almost equal in option 2. The sensitivity assessment showed that the maximum RS did not exceed maximum SS even if it was increased by 20% by taking into account potential errors or bias towards either.

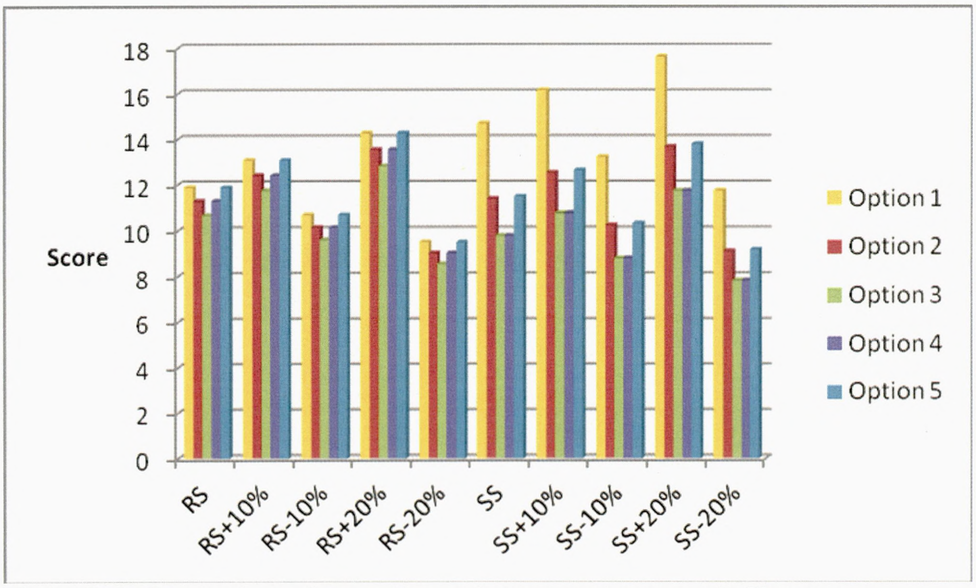


Figure 7- 2: Comparison of recreation and storm water scores in Skerryvore

The maximum SS for both the sub-catchments was higher than the maximum RS. This was due to all storm water indicators getting maximum scores, while all recreational attributes could not be allotted highest scores as the scoring for safety was in contrast to the scoring for water visibility and aesthetics. Option 1 would still remain the preferred option if there is an error of ± 20% for either storm water or recreational indicator weighting. Even if the recreational indicators are increased by 20% while storm water indicator is decreased by 20% or vice versa, option 1 would still get the highest score as its storm water indicators were might higher than other options and its recreation indicators were also higher than options 2,3, and 4 but equal to option 5.

Spateston Burn catchment

The Martlet sub-catchment showed that maximum storm water score corresponding to option 4 was higher than all recreational scores. This was similar to the results of the sub-catchments in the Light Burn catchment. However, the recreational scores of other options except option 4 were higher than respective storm water scores. The recreational scores of the options 1, 2 and 3 remained lower than their corresponding storm water management scores even after increasing them by 20 percent. This showed that the storm water scores were more sensitive to the changes in their attributes.

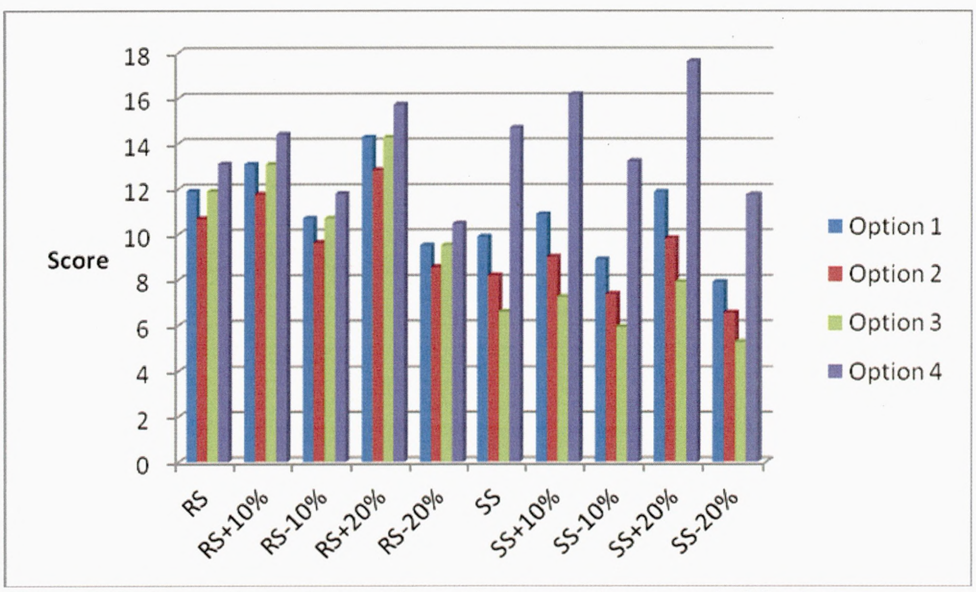


Figure 7- 3: Comparison of recreation and storm water scores in Martlet

Comparison of the recreational and storm water scores showed that all recreational scores were higher than the corresponding storm water scores for all the four options. This was due to the fact that, for all options, not more than 57% of the sub-catchments drained to the SUDS. Further, none of the Heron options had simultaneously maximum scores for all three storm water indicators.

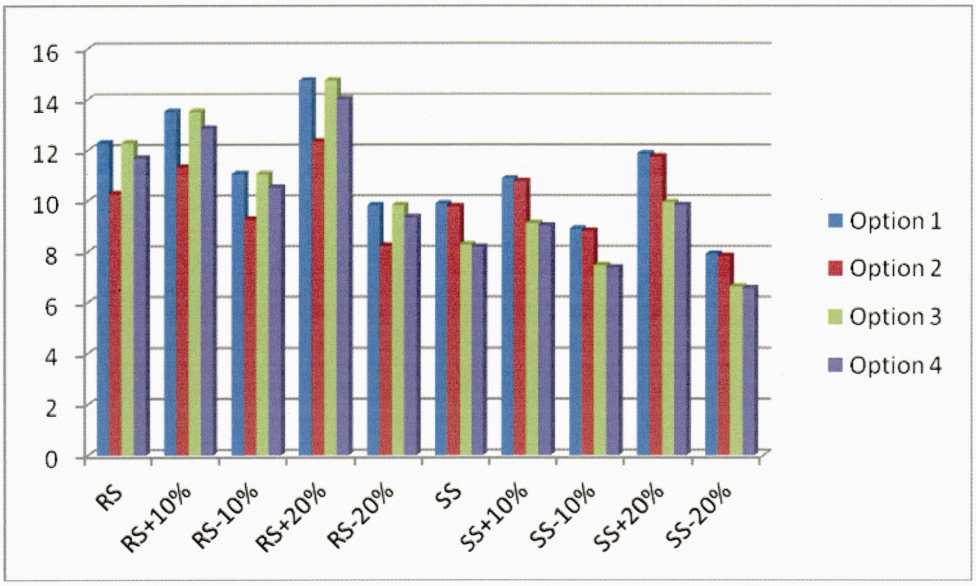


Figure 7- 4: Comparison of recreation and storm water scores in Heron

7.4 INTERPRETATION OF RESULTS

The results of the case studies have been interpreted in the context of existing research, current practices and in terms of the research questions initially adopted at the start of this research (section 1-1).

Distribution of green spaces for integrated water planning

Analysis of the two case study areas showed that the distribution of green spaces is an important consideration in the planning of SUDS. For example, section 5.4 shows that green spaces beside the watercourse were potential sites for SUDS (Table 5-3). In contrast, there were no green spaces beside the watercourse in Cardowan and thus no SUDS options were possible. Authors such as Davis and Mccuin (2005) have recommended the development of ponds and basins from a hydraulic perspective and SUDS options in Skerryvore and Martlet in sections 5.5 and 6.5 show the potential for the integration of water features into parks as it could provide areas for walking, playing and sitting nearby.

Option 3 of a detention basin in Skerryvore (discussed in section 5.5) offers multifunctional benefits as they are well connected and there are several recreational opportunities such as walking, playgrounds, schools in its vicinity. The potential for integration of detention basins within the landscape is also supported by Ferguson (1991), who suggests that SUDS can be moulded into integrated components of urban landscape in ways that provide aesthetic recreational, economic and ecological values. Macdonald and Jefferies (2003) studied detention basins at DEX in Scotland and found that most of the detention basins were well maintained, with cut grass and other vegetation, giving the appearance of small, tranquil areas of parkland. However, the basin options for Garthamloch noted in sections 5.7 and 6.7 do not provide multifunctional aspects due to the lack of other recreational facilities such as playgrounds, walking and sitting areas close to the site. If the proposed solutions are adopted it would be best to integrate the SUDS ponds or basins with other recreational improvements near the SUDS device.

The ponds in both case study areas were located in places such as Cranhill Park, or large amenity areas in the Spateston catchment. Regional ponds ideally require larger areas and could be suitable for parks or amenity areas if located in a low lying area. This approach to planning would be in consistence with the TCPA (2004) recommendation for the integration of SUDS biodiversity with urban parks. Although Apostolaki (2007), Ferguson (1991) and Macdonald and Jefferies (2003) have identified the benefits of SUDS in relation to amenity and biodiversity, they do not provide a methodology for integrated planning at the design stage unlike this research which utilizes green space planning within the six stage framework introduced in Chapter 3. The understanding of existing green space opportunities assist in recommending solutions with better integration potential. Further, a scoring system applied in stage 6 of chapters 5 and 6 helps in understanding the levels of recreational benefits associated with each option. As a result it provides a holistic design process for integrated storm water and green space planning.

Storm water indicators for integrated planning

The analysis of the storm water indicators showed that the different SUDS options affect the reduction of peak flows to varying extents. For example the significantly higher attenuation and long term volumes of option 5 at Garthamloch (Appendix B5, Figure 1) provided a much greater reduction in peak flows than other options. The type of SUDS used did not affect the reduction of peak flows but the peak flows were sensitive to changes in the return period mitigation shown by various indicators (Figure 5-19, Figure 5-20). Similarly, option 4 of Martlet shows greater peak flow attenuation (Appendix C5, Figure 1) justifying higher attenuation and long term storage scores. Both the case studies showed greater sensitivity to changes in the attenuation volumes than the other two storm water indicators. The results of the work are consistent with the principles of storm water flow mitigation measures discussed in DEFRA (2005). Investigations carried out as part of the DEFRA (2005) in England also indicated reduction of flows and attenuation and long term volumes were recommended to reduce flooding.

Amenity indicators for integrated planning

Amenity is an important element of SUDS, but the amenity aspects of SUDS are often neglected and addressing the planning of amenity for SUDS schemes was one of the main objectives of this research through the use of indicators for the planning. This section presents a discussion of the application of the indicators in the context of existing knowledge.

Accessibility

In the past there was a tendency to hide water in pipes, culverts and backyards whereas water is now being increasingly recognised as a resource (Debo and Reese 2003). Many urban planners use using water features SUDS and watercourses as focal points in town planning (Dreiseitl *et al.* 2001). In this context accessibility of SUDS features as identified in the framework will be of key importance as they provide an opportunity to celebrate water in urban landscape. CIRIA (2000) recommended accessibility mainly from the point of view of maintenance but it is also important from recreational point of view. This work shows how accessibility could be incorporated into various design through the SUDS options presented in sections 5.5 and 6.5.

Water visibility

The importance of water visibility has been recognised by various researchers such as Dunnett et al. (2002) and Apostalaki (2007). This research showed how attributes of water visibility could be used for developing SUDS options in the Light Burn and Spateston Burn catchment.

Aesthetics

Research carried out by Giles Corti *et al.* (2009) showed that people give high priority to aesthetics. The focus group incorporated into this research also gave a higher weighting for aesthetics among all recreational indicators except safety. This parameter was applied in various types of green spaces such as parks, amenity areas and its potential recreational benefits was assessed.

Passive surveillance

The SUDS options in Chapter 5 and 6 presented various levels of passive surveillance. This research has demonstrated a method for evaluating the location of SUDS in areas of varying potential for surveillance. The safety of residents can be improved by appropriate design of urban spaces (Gold, Revill 2000) making this research useful for planners to conceptualise safer locations of SUDS wherever feasible. The use of passive surveillance in addition to safety associated with the device provides greater appreciation of the concerns associated with safety.

Multi-functionality

The pond site at Cranhill Park in Skerryvore (section 5.5) could enhance the recreational value of the park. Parks with ponds have been designed for many cities including Seattle, USA to promote the multiple-use of these spaces (Johnson, Staheli 2007). The approach of integrating storm water with other recreational land use is also a key principle of the storm water management approach in Melbourne, Australia (Melbourne Water 2011). The focus group survey in this research discussed in chapter 4 confirmed that multi-functionality was considered as one of the most important parameter (with a score of 8 out of 10) in addition to safety by the planners and engineers. The approach considered in this research integrated multi-functionality of sites with that of the SUDS device in order to maximise the potential of the green spaces.

Safety

The SUDS options of ponds and detention basins in the two case studies (Chapter 5 and Chapter 6) provide examples of varying levels of safety hazards due to the presence of permanent pool of water. Safety hazards associated with SUDS devices have also been recognised by Burton and Pitt (2002) and CIRIA (2000). This research will be useful for planners to choose appropriate SUDS to the ensure safety of residents.

Ownership

Publicly owned green spaces were readily available in the two subject catchments. However, a site was also selected in the school in the Martlet catchment as it was required due the considerations of existing drainage layout and development plan. Preference for publicly owned land for planning of SUDS has also been expressed by Stovin (2007) who argues that privately owned land may be difficult to acquire for implementing SUDS.

Evaluating integrated green space and water planning

The tool for quantifying the benefits of SUDS amenity and storm water management was tested in the case study areas.

The benefits for peak flow reduction were measured using hydraulic simulations, which showed a reduction of peak flows in both areas. The modelling was also able to test the variations in recreational indicators associated with different options. The improved perception of green space benefits in the storm water features was based on factors such as addition of amenity value, biodiversity, aesthetic appeal, and recreational potential. Further, the combined recreational and water management assessment of the green spaces showed the integration possibilities.

Multifunctional potential of green space was based on several factors such as the distribution of development, distribution of green spaces within the catchment and in housing estates. For example, the green space near Black Cart in Ettrick was not accessible to residents due to the presence of railway line nor could be used for SUDS due the an embankment beside the railway line. Authors such as Herzele and Wiedemann (2003) and Jones *et al.* (2009), have indicated multiple purposes of green spaces but they have not identified the potential for integrating storm water management. However, the evaluation tool in this research provided a technique for integrated planning of green spaces with storm water management in urban areas.

Martin *et al.* (2007) developed a multi-criteria decision aid for best management practices or SUDS, based on stakeholder surveys. The decision tool of Martin *et al.* (2007) provides for the following criteria: technical, hydraulic, environmental, sociological, planning and economic. This tool can be useful to complement the works of authors such as Martin *et al.* (2007) as it could inform stakeholders about the recreational and storm water mitigation of potential SUDS options. However, this research was limited to ponds and basins and can only be used in catchments where these options are proposed.

7.5 COMBINING RECREATIONAL AND STORM WATER MANAGEMENT SCORING

The impact of the recreational and storm water indicators on total scores was analysed and the results are presented in this section.

Light Burn catchment

Option 5 had the maximum score among the five options in Garthamloch (section 5-7). In Option 5 all the storm water indicators had maximum attribute points unlike the other options. This option combined higher scoring attributes such as aesthetics and water visibility and greater contributing areas produced a great mitigation effect on 30 yr return period flows. However, option 3 had the maximum recreational score among all options, but had lower storm water and overall score than option 5 as shown in Figure 7-5.

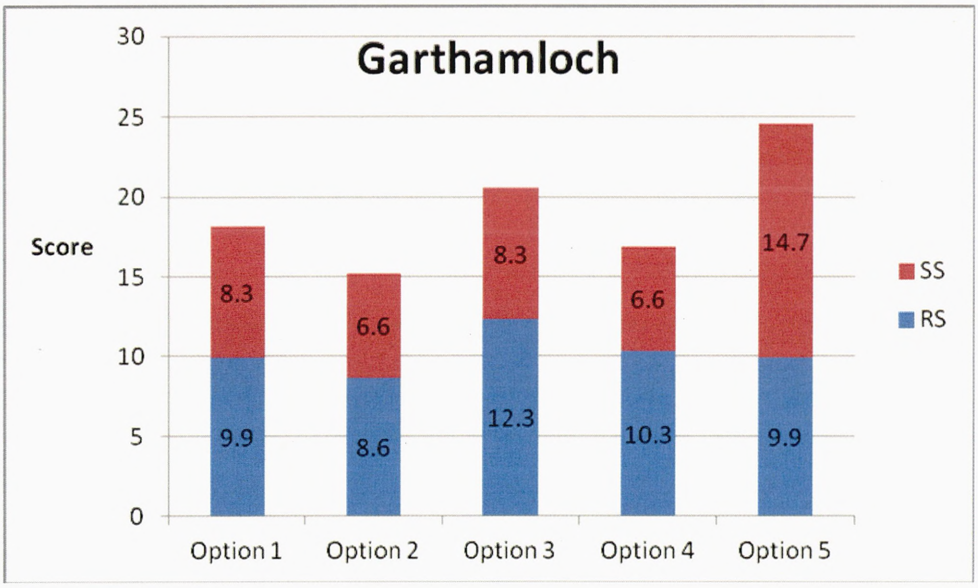


Figure 7- 5: Combining recreational and storm water scores in Garthamloch

The preferred option for Skerryvore also had a higher storm water score than its recrational score as shown in Figure 7-6. This was due to the high scoring attributes such as aesthetics, multi-functionality, better accessibility in the park in addition to larger contibution of impermeable areas into the SUDS. Inspite of the bias towards storm water scores, the scoring in Skerryvore was sensitivity to both types of indicators as the recreational scores were higher among three options (options 3, 4 and 5). As both recreational and storm water water was significantly higher in option 1, any changes in indicator attibutes of other options could at best match the score of option 1.

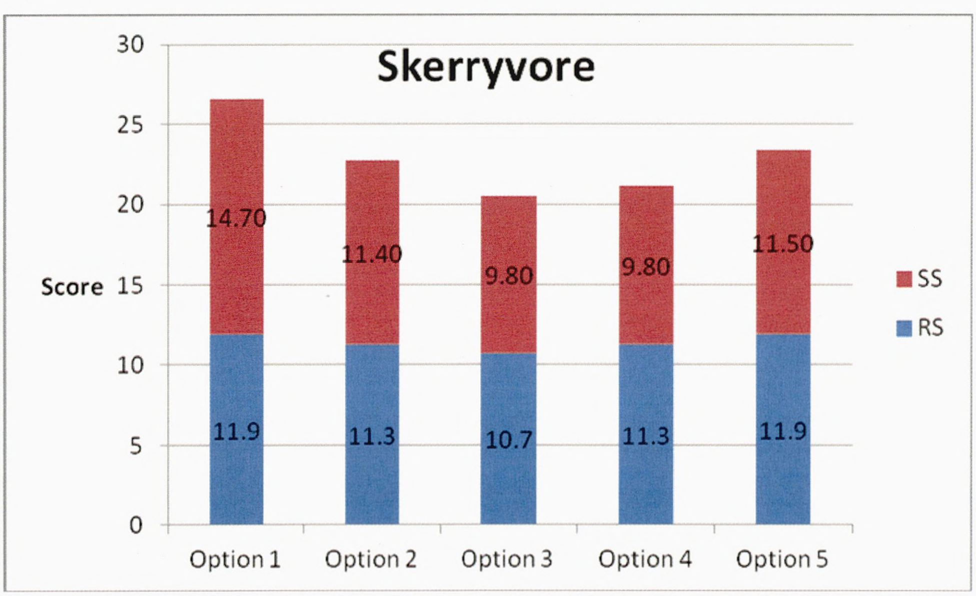


Figure 7- 6: Combining recreational and storm water scores in Skerryvore

Spateston Burn catchment

Option 4, preferred option in Martlet, combined maximum scores for both recreation and storm water (Figure 7-7). The high recreational scores for options 1, 2 and 3 showed more favourable opportunities associated with recreation (due to park setting with good access) than corresponding storm water attributes in these options. However, the significantly higher score of option 4 which had the highest storm water and higher recreation scores means that other options could not be modified to increase their score so that they are higher than option 4.

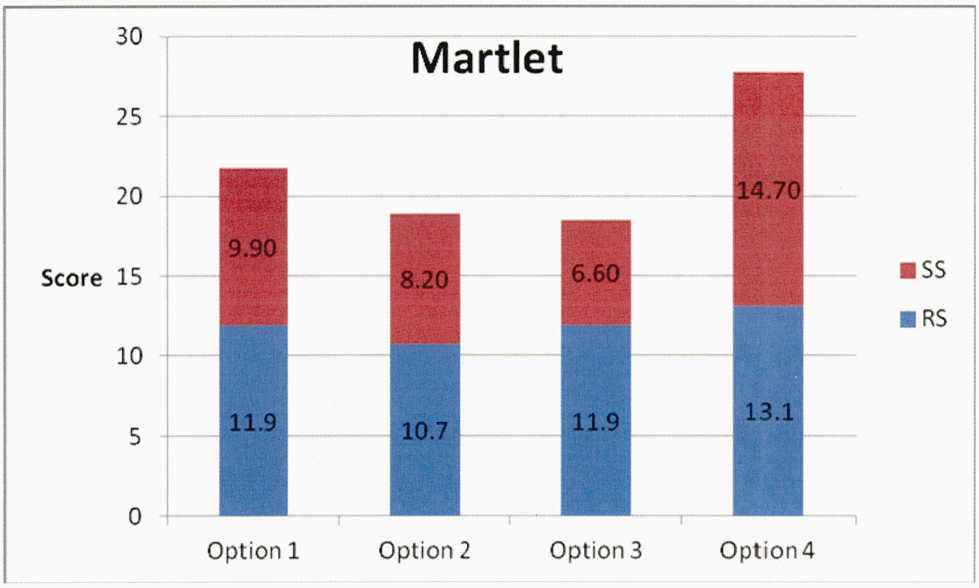


Figure 7- 7: Combining recreational and storm water scores in Martlet

In Heron the preferred solution was not biased towards higher storm water scores. In this subcatchment all recreational scores were higher than the corresponding storm water score for each option. This was due to the fact that there was very limited potential for SUDS for a significant portion of developed area. As a result the storm water scores were lower for each option than recreational scores (Figure 7-8). Although the score for option 1 was higher than the other three options there is little different between the scores and in the absence of option 1, any of the three options could be the preferred option for this subcatchment. Further, small errors in the score of any option could also lead to the change of the preferred option.

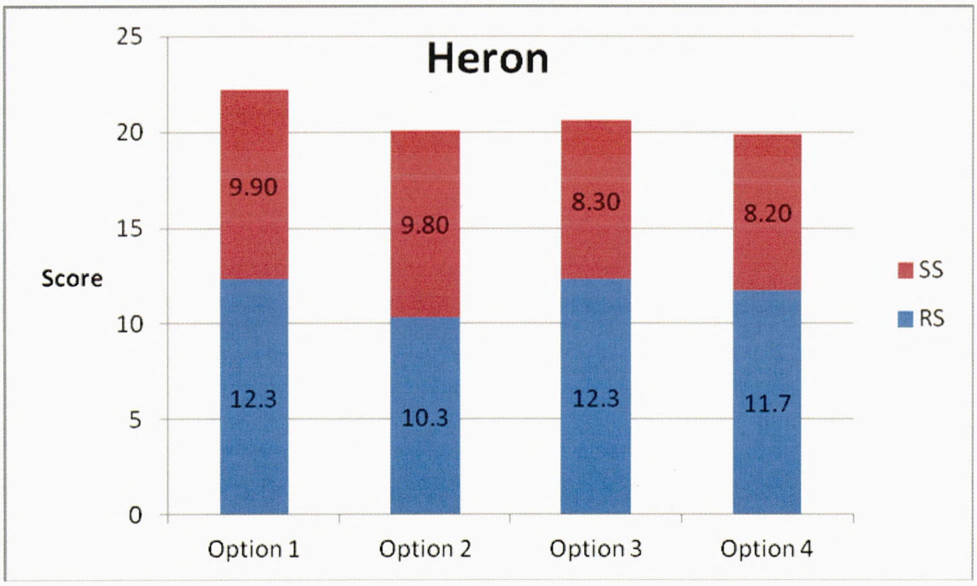


Figure 7- 8: Combining recreational and storm water scores in Heron

7.6 IMPLICATIONS FOR GREEN SPACE PLANNING

This research could inform development of water sensitive approach within standards for planning green spaces, as recommended by SPP and PPS 17. Such an approach would lay greater emphasis on synchronisation of the planning of green spaces and storm water management as illustrated by the application of the proposed integrated framework in the two case study areas.

In the past, water bodies have been a separate category in the planning of green space typology (Dunnett, Swanwick, and Woolley 2002) and, therefore, the multi-functional benefits of planning integrated spaces were not adequately highlighted. This possibly resulted in the exclusion of SUDS features from the planning of amenity and recreation areas. The case studies in sections 5.5 and 6.5 showed important recreational benefits associated with the use of ponds and basins could be understood using the indicators developed in chapter 4. The recreational potential of SUDS thus illustrated could be used by the green space planners for multi-functional SUDS in urban areas.

The scoring tool introduced in section 4.2 and tested in the two case studies in sections 5.7 and 6.7 shows comparative evaluation of recreational and storm water management benefits associated with SUDS options. In the past SUDS design often had poor recreational aspects associated with them (Fergusson 1991). This tool therefore can be useful for local authorities for maximising the recreational benefits of SUDS along with providing greater attenuation in the drainage network.

Land take has been considered an important element in urban design, with urban planners aiming to reduce it (Jenks *et al.* 1996). In cities, there is often competition for various uses for land, where green spaces and gardens generally receive less attention (Hall 2002). This methodology makes better use of land use by providing areas for flood management with integrated amenity benefits, thus reducing the need for additional land take for amenity areas. For example, various SUDS options in Garthamloch and Skerryvore uses existing green spaces to reduce flooding and corresponding land take. Integrating SUDS with green spaces therefore corresponds with the objectives of the local authorities in achieving sustainable drainage and enhancing amenity and recreation without additional land take.

7.7 PLANNING IMPLICATIONS FOR STORM WATER MANAGEMENT

The proposed methodology takes a holistic approach, not only of flood management, but also the provision of amenities and recreational facilities. It was felt that planning of sustainable storm water management lacked this knowledge, as was discernable from guidance documents such as CIRIA SUDS manual (2007) by Woods-Ballard *et al.* (2007), Sewers for Scotland (WRc 2007) and Sewers for Adoption (WRc 2006).

Other decision support tools can be linked to this methodology for providing other levels of planning. The proposals in this research provide a complementary approach to the work of Swan (2003), who adopted an infiltration-based approach. As the case study sites of Light Burn catchment and Spateston Burn catchment were located in impervious soil regions, this research is tested only for impervious areas and further research would be needed for linking it to infiltration. However, other research, such as that of Kaiser (1997) and Swan (2003), already provides useful knowledge for infiltration areas.

Implementation of integrated planning would require the pooling of resources from different departments and more joint working across disciplines. The integration of green spaces and water management would need co-operation from the local authority and water utility. Surface water management plans (SWMPs), as required by the Flood and Water Management Act (2010) and developed by various stakeholders led by the local authorities, could be used for developing integrated spatial plans. These plans could be integrated with a strategic green space network plan. For example, Glasgow City Council is developing a green network strategy for the city (Glasgow City Council 2010) and it could provide the opportunity for such integrated planning.

Most design guidance for storm water management fails to include integration of water attenuation and recreational features. This research identifies the possibilities for integration of amenity and recreational areas into basins and ponds. The research, therefore, could inform the development of improved guidance for SUDS and their integration into wider green spaces.

7.8 APPLICATION OF INTEGRATED GREEN SPACE AND WATER PLANNING

Previous approaches to water sensitive planning have emphasised the use of storm water management features for reducing floods and improving water quality (Coombes *et al.,* 2000; Wong 2006). This was possibly a result of their fragmented vision of SUDS. Although the SUDS triangle envisioned in CIRIA (2000) is based on the three aspects of quantity, quality and amenity, the focus of research has been mainly on quantity and quality ignoring the amenity aspects of SUDS and probably leading to reduced values of housing and landscapes (Lee and Li, 2009). The greater preference for SUDS with higher recreation potential as shown in section 5.7 and section 6.7 would also enhance housing value based on the research of Lee and Li (2009). However, more research may be needed to further analyse any relationship.

This research takes a step further the insights of Kaiser (1997), which focussed on the urban design principles (which depends on the amount of green spaces). The methodology in this work considers a range of green spaces and identifies dual use scenarios based on their distribution and functions. Thus, the main focus of this work is green space and storm water management unlike Kaiser (1997) whose approach was related to overall urban design.

The integrated open space and water planning framework discussed in chapters 3 and 4 can form a link between higher urban planning and design and detailed planning of storm water management and green space planning as shown in Figure 7-1. The framework would inform development of SWMP and green network plans of local authorities and vice-versa.

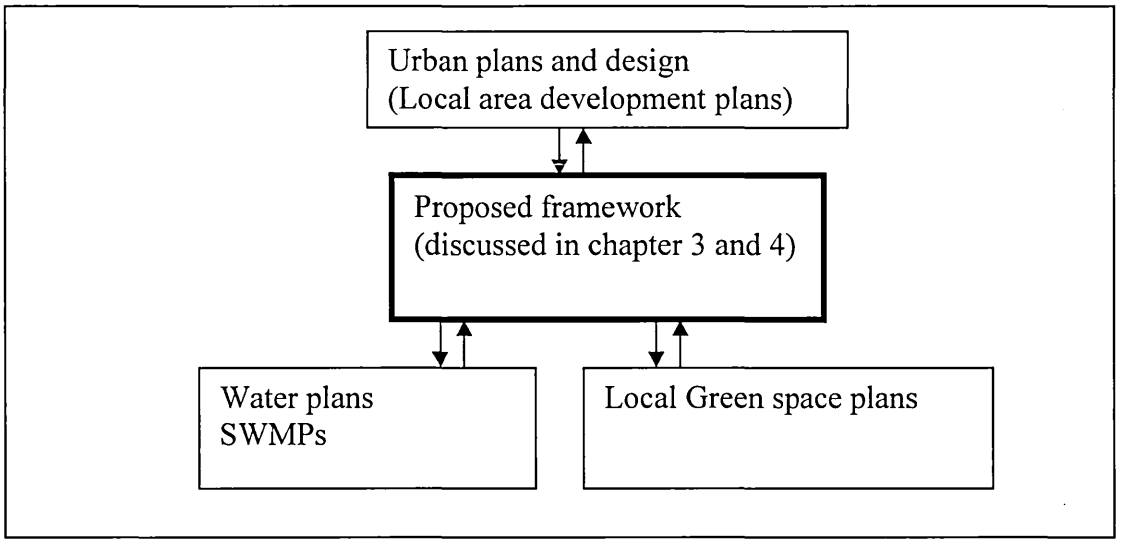


Figure 7- 9: Proposed framework acts as an interface between the higher principles of urban planning and detailed planning of water and green spaces.

This framework is applicable for outer urban areas with good amounts of green spaces, where the potential for multiple use exists and it is not applicable to inner city areas as there are likely to be insufficient green spaces. As seen from the case study examples in sections 5.4 and 6.4, Cardowan and Ettrick lacked sufficient green spaces or were not suitable for SUDS implementation based on the proposed methodology. However, areas with few open spaces may potentially have underground storage as a feasible option.

7.9 LIMITATIONS

There were several limitations associated with this research emerging from assumptions in the research, time constraints, data limitations and other methodological issues. These were:

1. The conceptual methodology has been applied to two catchments to represent different possibilities for the planning of green spaces. However, this methodology would need to be applied to many other catchments to reach the stage of generic application in urban planning.

2. The scores and weightings associated with each storm water indicator attribute identified in section 4.2 were not exactly proportional to their impacts on peak flows (Appendix B5 and Appendix C5). A greater number of scenarios could have resulted in an improved sensitivity analysis of the indicators. However, the presented scenarios do indicate that the basic principles can be applied in to study the potential for reduction in peak flows in catchments.

3. Only preliminary hydraulic modelling of the case study catchments was carried out. The aim of the research was to test the initial feasibility of integrated planning at the spatial level and it was considered that basic modelling would be sufficient for the purpose.

4. No detailed qualitative analysis of green space quality was carried out as part of this research due to lack of time and resources and the criteria used in the qualitative research of sites were based on previously established research. Although SUDS were likely to improve the amenity value of the various green spaces in the case study catchments, further investigation was outside the scope of this study. Future investigations could, however, be undertaken by other researchers to study the improvement of existing green space amenity and biodiversity potential through the development of SUDS features.

5. This research did not include biodiversity indicators in the planning of integrated storm water management features. The review of research showed significant existing research outputs on ponds by various researchers, such as Viol *et al.* (2009), Heal (2010), Biggs *et al.*(2000). However, the research on other forms of SUDS, such as detention basins, bio-retention basins, swales and rain-gardens, was too sparse to develop indicators. Consequently, it is recommended that future research should focus on understanding the

biodiversity potential for all forms of SUDS so that biodiversity planning indicators could be introduced.

6. Implementation of the storm water disconnection scenarios in the Light Burn catchment may be difficult for various reasons. Construction of swales in front or back gardens of built up areas would require the agreement of all householders within the housing estates. However, areas with separate sewers draining into combined sewers can be easily disconnected into the surface water system.

8 CONCLUSIONS

8.1 INTRODUCTION

This chapter presents the overall conclusion of the research project. The major outcomes are presented in section 8.2. Recommendations for sustainable planning are enumerated in section 8.3. The advancement of knowledge due to this work has been discussed in section 8.4. Section 8.5 presents the need for future research.

8.2 MAJOR OUTCOMES

Application of the framework in the Light Burn and Spateston Burn catchments indicated the possibility of development of water sensitive plans based on this integrated approach which was reflected on in chapter 7. The major conclusions associated with the application of the conceptual framework and methodology in the two case study areas are presented below:

- This research demonstrated that overall framework introduced in section 3.2 consisting of the six stages can be applied in two catchments with different patterns of development and topography. This indicates its potential for wider use in sub urban areas of various cities.

- Suitable distribution of green spaces in a particular sub-catchment was an important factor facilitating SUDS planning in catchment. This research indicates the need for catchment oriented green space distribution. Presence of green spaces downstream of residential estates and other developments favoured the development of SUDS. The research showed through examples how the needs of recreation can be harmonised with storm water management.

- SUDS options can be designed using both recreational and storm water indicators (shown section 5.5 and section 6.5). Such an approach can be used by landscape designers and engineers to jointly develop more functional green spaces.

- The methodology from DEFRA (2005) was used for planning of various SUDS options after studying the patterns of flooding using a hydraulic model. The model was used as a tool to further test the attenuation benefits of storm water management. This methodology in both the study catchments resulted in developing SUDS options for reducing peak flows. This showed that the integrated spatial planning of SUDS can be carried out along with hydraulic modelling for testing storm water management benefits.

- SUDS were used in existing green spaces in upstream areas to reduce the peak flows (section 5.6 and section 6.6). This showed that catchment approach to spatial and drainage planning can resolve flooding issues in an integrated manner. The peak flow reductions showed greater sensitivity to the indicator attenuation volume than the other two indicators flood return period and long term volume.

- The integrated scoring tool was applied in the two case areas showing its potential for wider application. The scores associated with the different SUDS options in chapter 5 and chapter 6 showed sensitivity to the spatial plan, type of SUDS and amount of attenuation provided. Thus, it can be used to assess the trade-off of amenity, ecology and drainage engineering. Application of the tool in the case studies showed its potential for planning integrated SUDS schemes. It could, therefore, be a tool for holistic green space design.

8.3 RECOMMENDATIONS FOR SUSTAINABLE SPATIAL PLANNING

A number of recommendations are made here for implementing the research in practice. These recommendations are based on the testing of the proposed methodology and subsequent evaluation in the context of the existing spatial and drainage planning frameworks.

The recommendations, as presented in this section, are classified into four categories: integrated water and green space planning framework, water sensitive green space planning, integrated storm water and green space indicators, integrated evaluation tool, and joint working groups. These recommendations may be of interest to planners and engineers involved in green space planning, development planning and drainage planning. Follow up of these recommendations will lead to improved planning of flood management in urban areas. Based on the feedback from local authorities, it was evident that there is a need for legislative changes to enable local authorities to enhance their roles at the planning stage of sustainable storm water management. It is also advocated that institutional changes should be carried out to improve the planning mechanism for more SUDS planning.

The recommendations made here apply only for the catchments which lie in suburban residential areas and have impermeable soils as investigated in case studies in chapter 5 and chapter 6. Various other issues affecting its applicability have been discussed in section 7.6.

A summary of the main recommendations of the research, based on discussions with various stakeholders, are presented in below.

- The integrated green space and water planning framework can be used this framework for other suburban residential catchments as applied in this research (chapter 5 and chapter 6).

- Develop green spaces such as parks and amenity areas downstream of housing estates and institutional areas. It was shown in the case study sub-catchments of Skerryvore and Martlet that SUDS proposed in such green spaces achieved higher score due to greater multifunctional potentiality as well as higher attenuation potential (section 5.4 and section 6.4).

- Use recreational and storm water indicators to design and plan SUDS schemes as illustrated in section 5.4 and 6.4.

- Use the integrated evaluation tool for evaluating various SUDS options. The use of this tool has demonstrated that the various recreational and storm water attributes can be analysed and evaluated using a scoring system (refer to section 5.7 and section 6.7).

- Create joint working groups involving planners and engineers based on the overall framework shown in Figure 3-1. Awareness should also be generated among planners and engineers on various aspects of the methodology as discussed in chapter 3 and chapter 4.

8.4 ADVANCEMENT OF KNOWLEDGE

The main aim of this research was to develop a framework for integrated planning of SUDS and green spaces. When implementing drainage planning, engineers often do not understand the planning implications of various SUDS options. This research has investigated a new area of integrating storm water planning and green space planning at the design stage. It has examined the issues involved in green space planning, which has a bearing on green space and drainage planning, and has developed an integrated framework to be used by both planners and engineers.

This research has developed a novel integrated evaluation tool for assessment of amenity, and engineering issues associated with various schemes. The assessment would help in identification of drainage schemes to maximise the potential for amenity and biodiversity, while also maximising the cost saving potential. The results of case studies show how the tool was used for evaluation of SUDS options like ponds and detention basins for each site.

In addition to the integrated design of SUDS this research also showed the importance of analysing quantitative green spaces and other land uses for water sensitive planning. Investigations by previous researchers such as Apostolaki (2007), Lee and Li (2009) have not advocated a integrated water sensitive approach for green space planning. This approach advances water sensitive planning approach within the discipline of urban design as it would help in designing schemes, which would serve both functions of water storage and recreation. As green infrastructure is receiving increased attention in urban design, and areas with ecological and amenity qualities are being promoted (Moughtin, Shirley 2005), this research provides the knowledge to further boost development of higher quality water sensitive green spaces in existing urban areas.

8.5 THE NEED FOR FUTURE RESEARCH

This research has focussed on developing, testing and evaluating the proposed framework for water sensitive planning. It shows strategies for improving spatial planning for accommodating storm water needs. The work has created an area where a lot a future work could be undertaken to further improve the understanding of water sensitive urban planning.

1. In this work the conceptual framework was evaluated on two catchments. More catchments with different land uses (such as commercial and industrial) and development conditions should be studied to build a greater understanding in such situations.

2. This research was applied in impermeable areas and its scope for permeable areas could be a subject area of future research. In permeable areas rain gardens, soakaways, filter drains and pervious surfaces could be important storm water management options for reducing peak flows. The potential for integration of these devices with recreational indicators could widen the scope of this research.

3. Future research should also examine economic aspects of integrated SUDS planning, both in new and existing developments. This would help compare the cost of such schemes with conventional schemes. Further, the benefits of amenity and ecology should be costed in order to understand the benefits of integrated schemes compared with separate schemes for green spaces and drainage systems.

4. Further research would need to be carried out to include water quality and biodiversity indicators into the evaluation tool. Although extensive past research has been carried out on water quantity indicators associated with storm water systems, due to time constraints, the study could not include those indicators. Biodiversity aspects of SUDS require further research for identification of biodiversity indicators.

5. This work was mainly focussed on establishing the application of the framework as well as the principles involved in the integrated evaluation tool and using limited SUDS types such as ponds and detention basins. However, future research should be undertaken to investigate incorporation of other SUDS types such as swales, bio-retention areas, and infiltration systems.

6. There is a need for future research to include consider integration possibilities at the level of source control which includes house gardens, school amenity areas, community centres, church yards, and other such areas. Such research will widen the framework introduced in this study.

7. There is a potential for further research to optimise the scoring for storm water indicators. The study could involve a large sample of hydrographs from a number of catchments to study its implications on the scoring system.

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APPENDICES

APPENDIX A: DATA AND CALCULATIONS ASSOCIATED WITH THE RESEARCH METHODOLOGY (CHAPTER 4)

APPENDIX A1: INDICATOR SURVEY QUESTIONAIRE

1. Score (scale of 1 to 10) the relative importance of each theme associated with SUDS (sustainable urban drainage such as ponds, basins, ditches) planning.

Theme	Weight	Comments
Amenity		
Storm water management		

2. Provide weight (scale of 10)for each indicator associated with amenity planning of SUDS

	Amenity Indicators	Weight	Comments
1	Access (roads, footpaths nearby)		
2	Water visibility (visible water on surface example. pond)		
3	Aesthetics (associated scenic beauty)		
5	Passive security (houses, schools, roads etc nearby)		
6	Multi-use (play, storage, biodiversity)		
7	Safety (risk of drowning)		
8	Ownership (whether public, institutional, private)		

3. Provide weight (scale of 10) for each indicator associated with storm water planning of SUDS

	Storm water Indicators	Weight	Comments
1	Levels of attenuation (2yr storage-1level, 2 yr and 10 yr-2 levels, 2 yr,10yr and 30 yr storage- 3levels)		
2	Attenuation storage (limits runoff similar to Greenfield)		
3	Interception volume(storage from leaves, grasses and trees)		
4	Long term storage (infiltration storage in soil)		
5	Peak Flow(max. flow in receiving water)		

APPENDIX A2: INPUT DATA FOR CONCEPTUAL SUDS EXAMPLE

Appendix A2 Table 1: **Regional Input data**

	Parameter	Units	Notations	Value
1	Hydrological Region	-	R	2
2	Soil type	-	S	4
3	Annual Rainfall	(mm)	SAAR	1000
4	Soil Runoff Coefficient	-	SPR	0.47
5	Climate Change Factors	-	CC	1.1
6	Attenuation Storage volume per unit area	(m^3/ha)	Uvol1yr	56
7	Atten. Storage volume per unit area	(m^3/ha)	Uvol2yr	70
8	Atten. Storage volume per unit area	(m^3/ha)	Uvol5yr	90
9	Atten. Storage volume per unit area	(m^3/ha)	Uvol10yr	100
10	Atten. Storage volume per unit area	(m^3/ha)	Uvol20yr	125
11	Atten. Storage volume per unit area	(m^3/ha)	Uvol30yr	136
12	Atten. Storage volume per unit area	(m^3/ha)	Uvol100yr	174
13	Atten. Storage volume per unit area	(m^3/ha)	Uvol200yr	197
6	FEH Rainfall factor	-	FF1yr	1.1
7	FEH Rainfall factor	-	FF2yr	1.1
8	FEH Rainfall factor	-	FF5yr	1.1
9	FEH Rainfall factor	-	FF10yr	1.1
10	FEH Rainfall factor	-	FF20yr	1.1
11	FEH Rainfall factor	-	FF30yr	1.1
12	FEH Rainfall factor	-	FF100yr	1.1
13	FEH Rainfall factor	-	FF200yr	1.1
14	Storage Volume Ratio	-	SVR 1yr	1
15	Storage Volume Ratio	-	SVR 2yr	1
16	Storage Volume Ratio	-	SVR 5yr	1
17	Storage Volume Ratio	-	SVR 10yr	1
18	Storage Volume Ratio	-	SVR 20yr	1
19	Storage Volume Ratio	-	SVR 30 yr	1
20	Storage Volume Ratio	-	SVR 100yr	1
21	Storage Volume Ratio	-	SVR 200yr	1
22	Hydrological Region Volume storage ratio	-	HR1yr	1
23	Hydrological Region Vol. storage ratio	-	HR2yr	1
24	Hydrological Region Vol. storage ratio	-	HR5yr	1.03
25	Hydrological Region Vol. storage ratio	-	HR10yr	1.05
26	Hydrological Region Vol. storage ratio	-	HR20yr	1.06
27	Hydrological Region vol. storage ratio	-	HR30yr	1.07
28	Hydrological Region vol. storage ratio	-	HR100yr	1.08
29	Hydrological Region vol. storage ratio	-	HR200yr	1.10
30	Long term Storage Factor	-	LTF	3
31	Rainfall depth	(mm)	RD	55
32	5 year/60 min rainfall depth	(mm)	M560	17

Appendix A2 Table 2: Local Input data

Parameter	Value
Area (ha)	16
Public open spaces (ha)	5
Developed area (ha)	11
Percentage imperviousness, PIMP (%)	0.6
Proportion of impervious area requiring storage, ALPHA	1
Impermeable area, AP (ha)	6.6

APPENDIX B: DATA AND CALCULATIONS FOR LIGHT BURN CASE STUDY (CHAPTER 5)

APPENDIX B1: CATCHMENT LAND USE AND DRAINAGE ASSESSMENT

This Appendix shows photos and maps of land use and photos of various sub-catchments in the Light burn catchment. Figures 1 to 7 indicates various aspects indicate land use and drainage aspects of Garthamloch. Similar aspects for the Skerryvore and Cardowan sub-catchments are shown in Figures 8 to 12 and Figures 13 to 17 respectively.

Garthamloch

Error! Reference source not found. shows the spatial planning of Garthamloch catchment indicating distribution of various land uses. The photo locations for Garthamloch for Figures 3 to 6 are indicated in Figure 2. Photos of typical housing blocks in Garthamloch are presented in Figures 3 to 6. The drainage layout is shown in Figure 7.

Appendix B1 Figure 1: Spatial planning in Garthamloch
(Map source: Glasgow City Council)

Green spaces are distributed in the outer mainly in the periphery of the sub-catchment. Although, there are some open spaces within the development, they are undergoing development.

Appendix B1 Figure 2: Photo locations for Garthamloch (Appendix B1 Figures 3 to 6)
(Map Source: Glasgow City Council)

Appendix B1 Figure 3: Inishail Road housing, Garthamloch

(Source: Google Street view)

Appendix B1 Figure 4: Guildford Street

(Source: Google Street view)

Large open spaces are directly draining into the roads as shown at Guildford Street with attenuation.

Appendix B1 Figure 5: Mosswale Rd housing

(Source: Google Street view)

Appendix B1 Figure 6: Mossvale Rd School

(Source: Google Street view)

There are incidental green spaces around buildings could provide opportunities for source control SUDS.

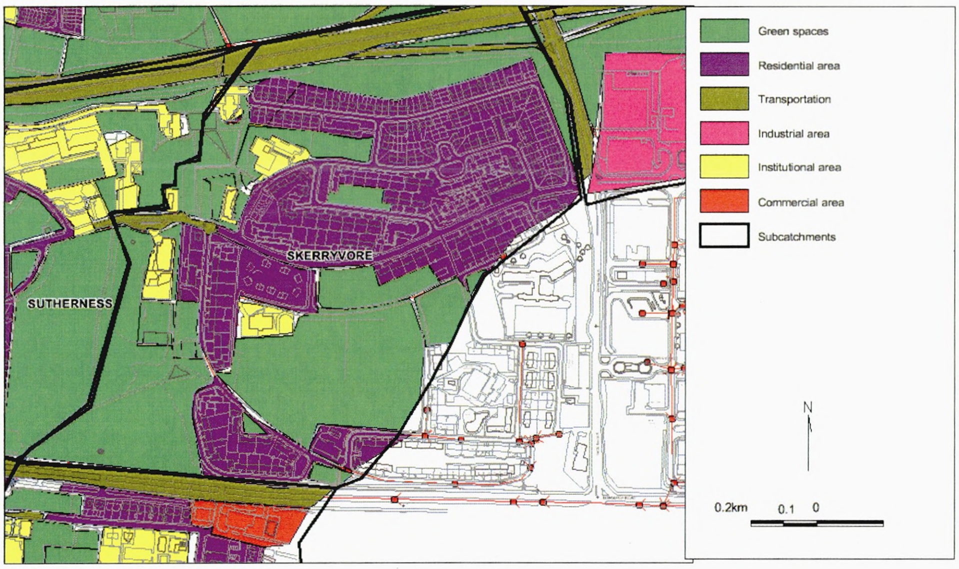
Appendix B1 Figure 7: Garthamloch sewer layout

(Map source: Glasgow City Council)

The western part of this sub-catchment contains separate sewers while the eastern part contains combined sewers. Separate sewered areas could be more easily retrofitted than the combined system areas.

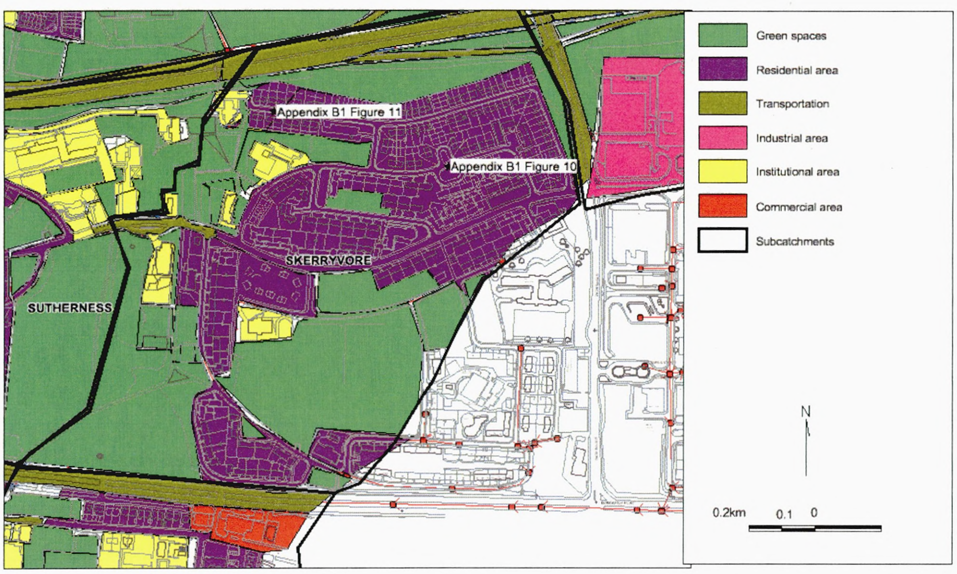
Skerryvore

Figure 8 shows the spatial planning of Skerryvore catchment indicating distribution of various land uses. The photo locations for Skerryvore for Figures 10 and 11are indicated in Figure 9. Photos of typical housing blocks in this sub-catchment are presented in Appendix B1, Figure 10 and Figure 11.The drainage layout of Skerryvore is presented in Figure 12.



Appendix B1 Figure 8: Spatial planning in Skerryvore

(Map source: Glasgow City Council)



Appendix B1 Figure 9: Photo locations for Skerryvore (Appendix B1 Figures 10 and 11)

(Map source: Glasgow City Council)

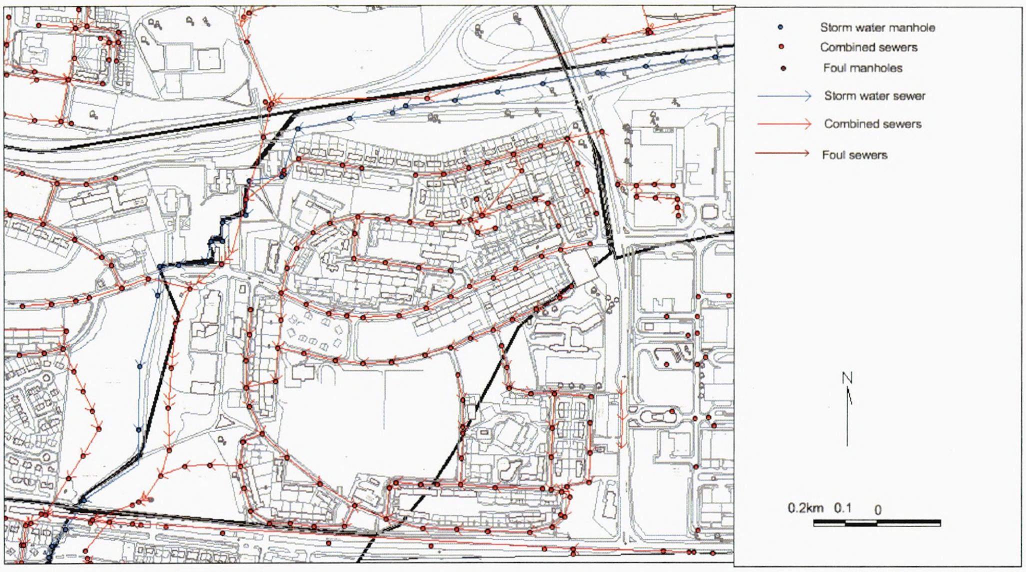
Appendix B1 Figure 10: Lamlash Crescent estate showing tenement housing.

(Source: Google Street view)

Appendix B1 Figure 11: Longstone Rd semi detached housing.

(Source: Google Street view)

The housing estates are having small gardens and very little incidental green spaces. Multiple housing types are present such as tenements, semi-detached and detached housing. There are insufficient opportunities for source control SUDS except in private gardens.

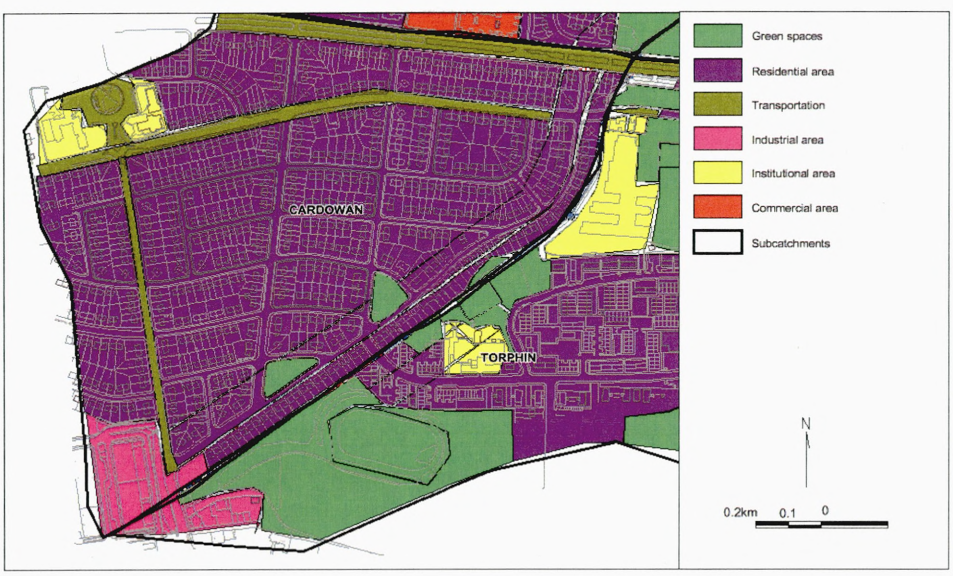


Appendix B1 Figure 12: Skerryvore sewer layout

(Map Source: Glasgow City Council)

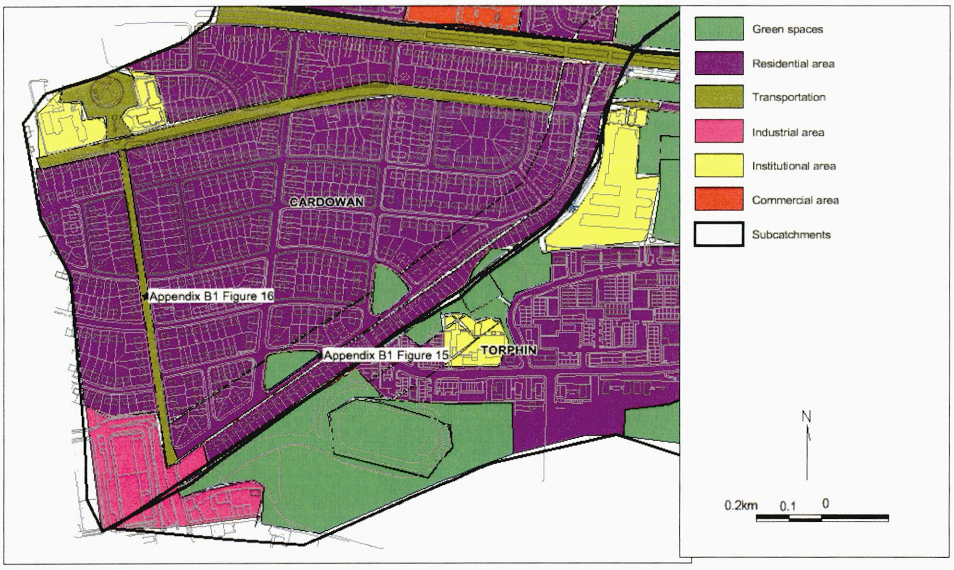
Cardowan

Figure 13 shows the spatial planning of Cardowan catchment indicating distribution of various land uses. The photo locations for Cardowan for Figures 15 and 16 are indicated in Figure 14. Photos of typical housing blocks are shown in Figure 15 and 16. The drainage layout of Skerryvore is presented in Figure 16.



Appendix B1 Figure 13: Spatial planning in Cardowan

(Map Source: Glasgow City Council)



Appendix B1 Figure 14: Photo locations for Cardowan (Appendix B1 Figures 15 and 16)

(Map Source: Glasgow City Council)

Appendix B1 Figure 15: Cardowan Road

(Source: Google Street view)

Appendix B1 Figure 16: Carntynehall Road.

(Source: Google Street view)

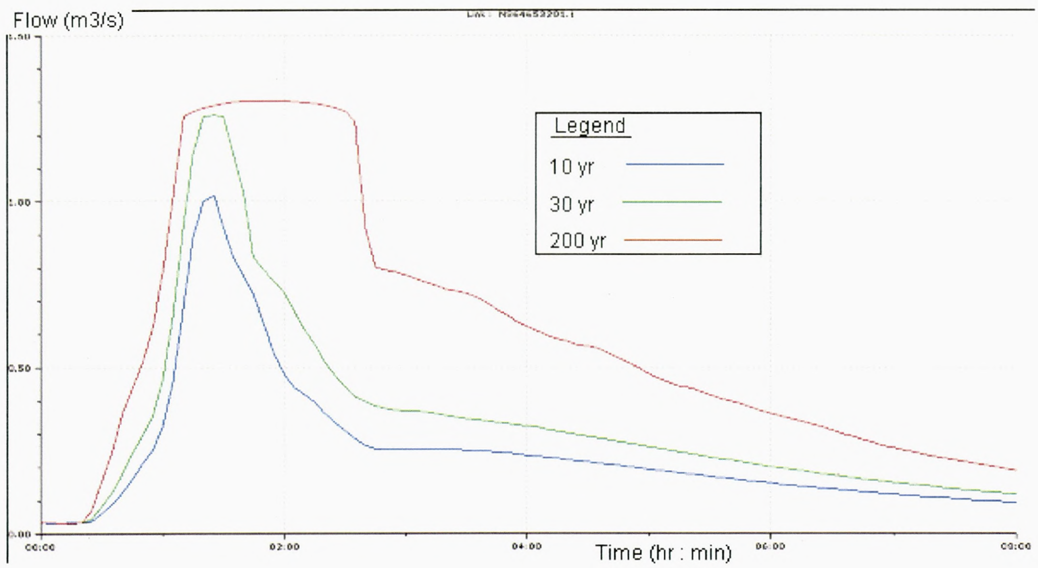
Housing is semi-detached and detached with both front and back gardens. There are very few communal green spaces.

Appendix B1 Figure 17: Cardowan sewer layout

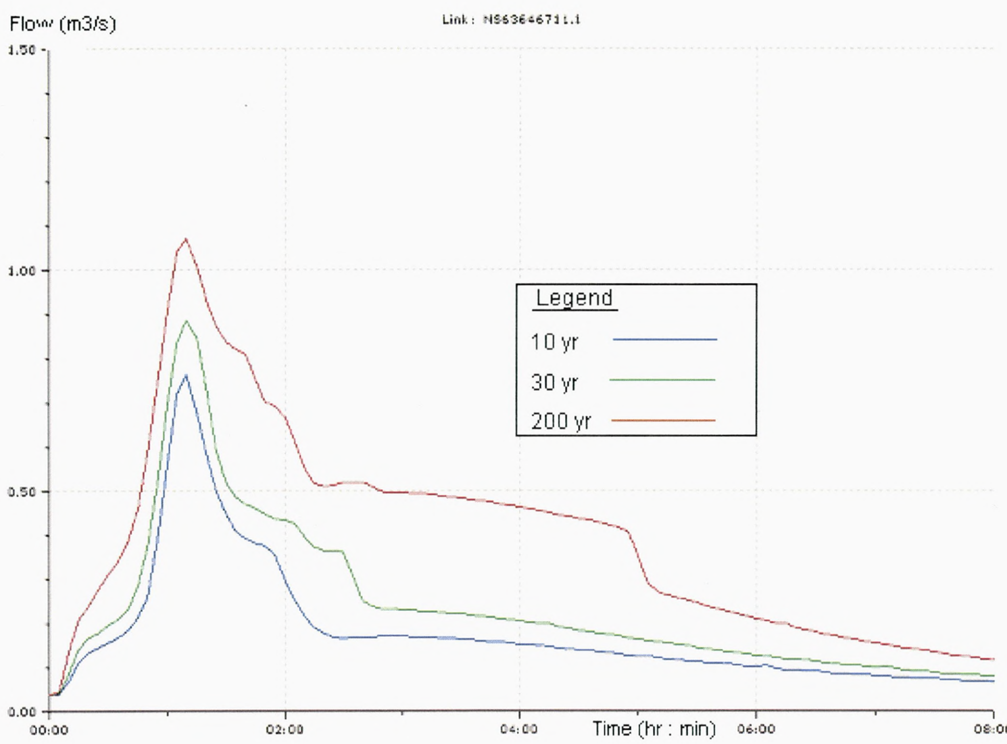
(Map Source: Glasgow City Council)

APPENDIX B2: HYDRAULIC ASSESSMENT

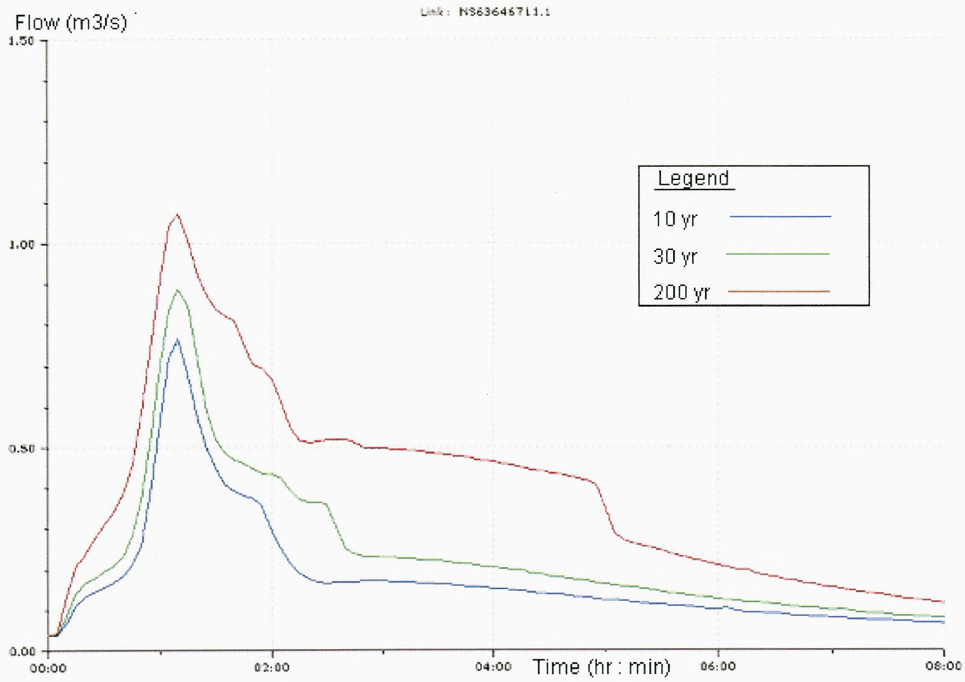
The existing peak flows downstream of selected catchments were determined as discussed in section 5.3 of Chapter 5. The hydrographs at downstream ends for the selected subcatchments are shown in Figures 1, 2, 3 while their topographies are presented in Figures 4, 5 and 6.



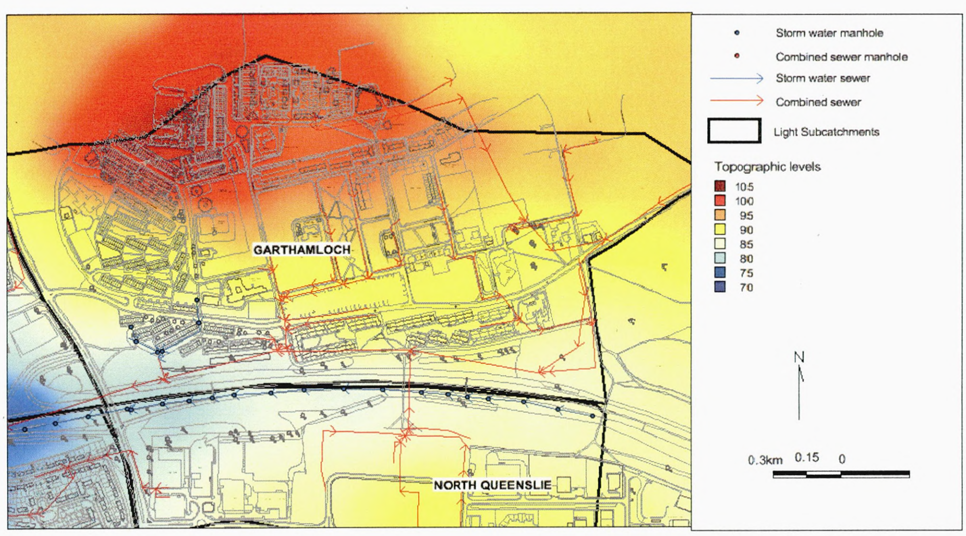
Appendix B2 Figure 1: Existing Peak flows at the outlet of Garthamloch for critical storm of 2 hr storm.



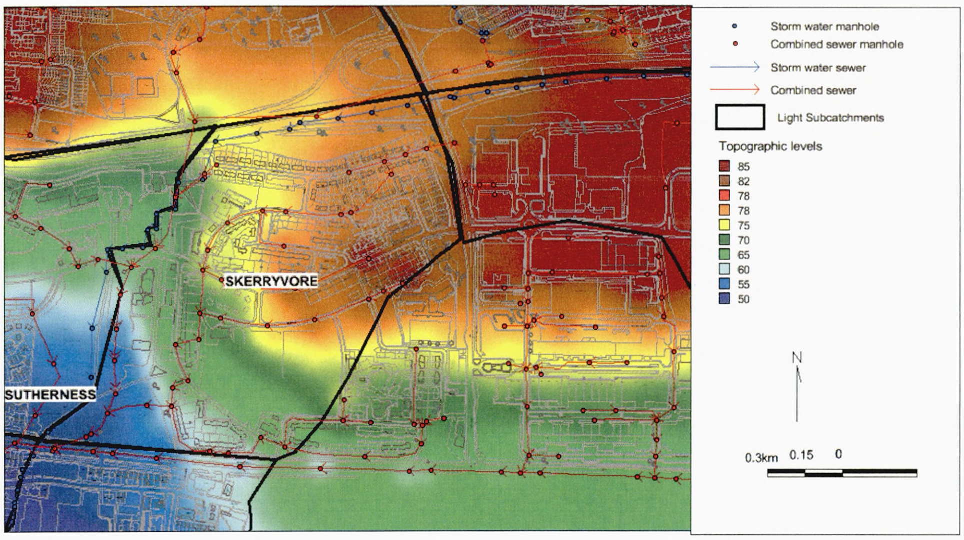
Appendix B2 Figure 2: Existing Peak flow at outlet of Skerryvore for critical storm of 2 hr storm.



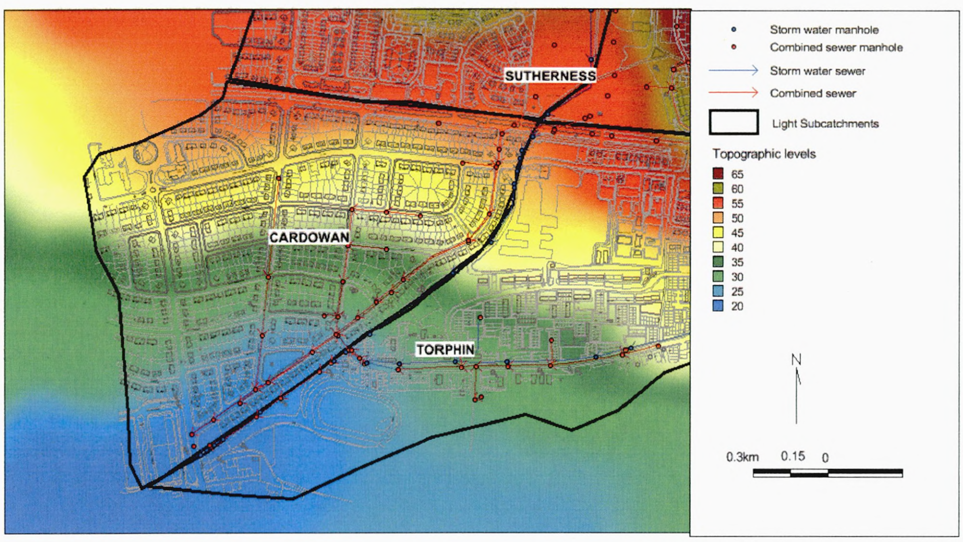
Appendix B2 Figure 3: Existing Peak flow at outlet of Cardowan for critical storm of 2 hr storm.



Appendix B2 Figure 4: Topography and drainage in Garthamloch



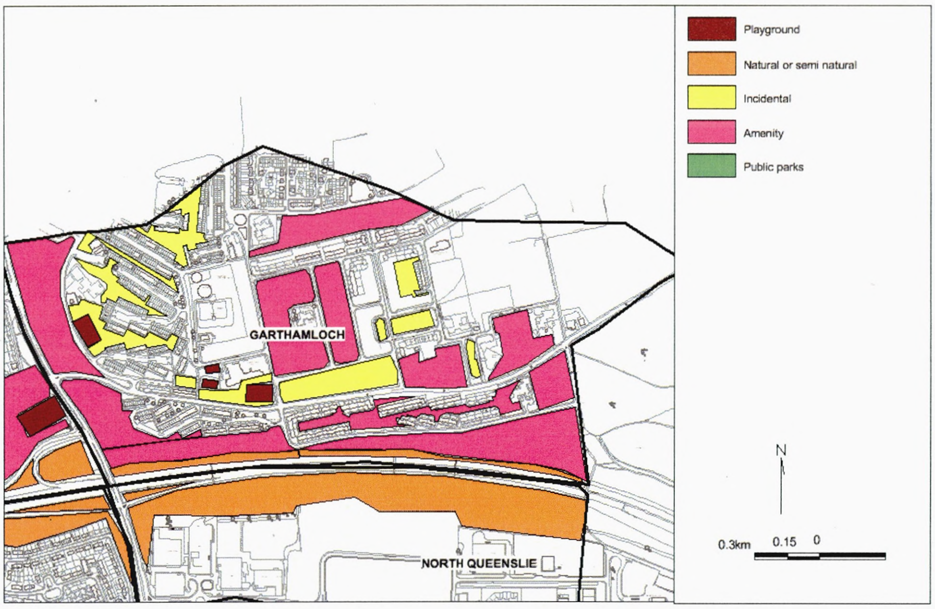
Appendix B2 Figure 5: Topography and drainage in Skerryvore



Appendix B2 Figure 6: Topography and drainage in Cardowan

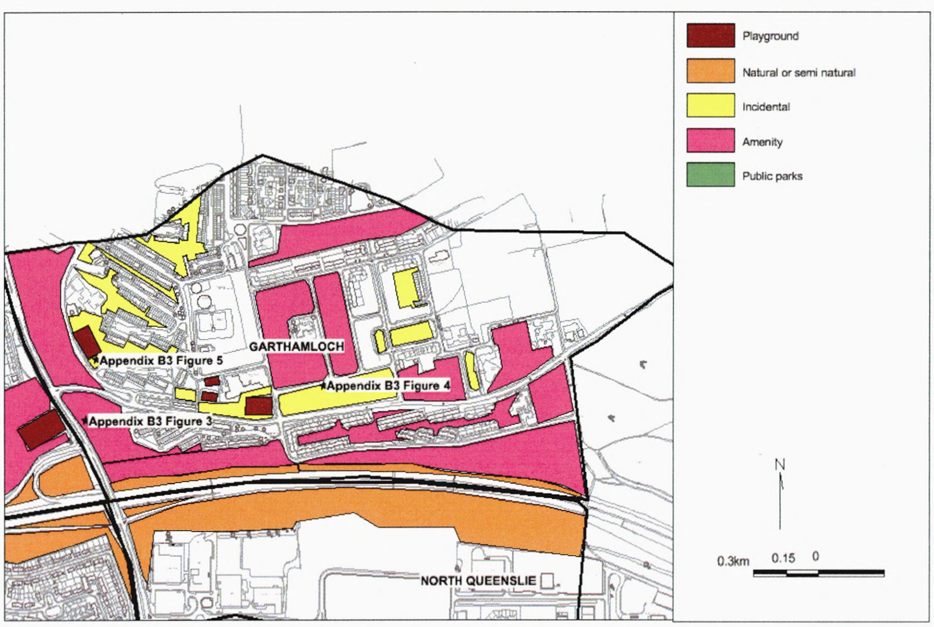
APPENDIX B3: GREEN SPACE ASSESSMENT RESULTS

This section presents illustrations for green spaces in the selected sub-catchments. Figures 1 to 5 shows the types of green spaces in Garthamloch, while figures 6 to 10 illustrate the green spaces in Skerryvore. Spatial plan in Cardowan is shown in Figures 11.



Appendix B3 Figure 1: Spatial green space planning in Garthamloch
(Map Source: Glasgow City Council)

There are potential sites suitable for planning of SUDS in the south of the sub-catchment.



Appendix B3 Figure 2: Photo locations for Garthamloch (Appendix B3 Figures 2 to 4)
(Map Source: Glasgow City Council)

Appendix B3 Figure 3: Stepps Road amenity green space

(Source: Google Street view)

Appendix B3 Figure 4: Inverlochy Street amenity space

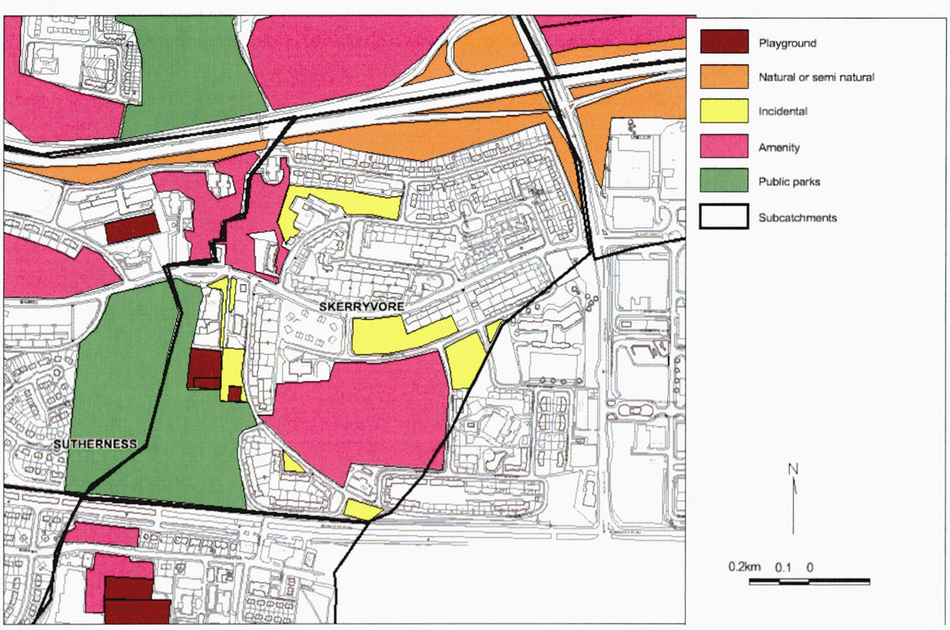
(Source: Google Street view)

Appendix B3 Figure 5: Incidental amenity spaces near Kishorn Place

(Source: Google Street view)

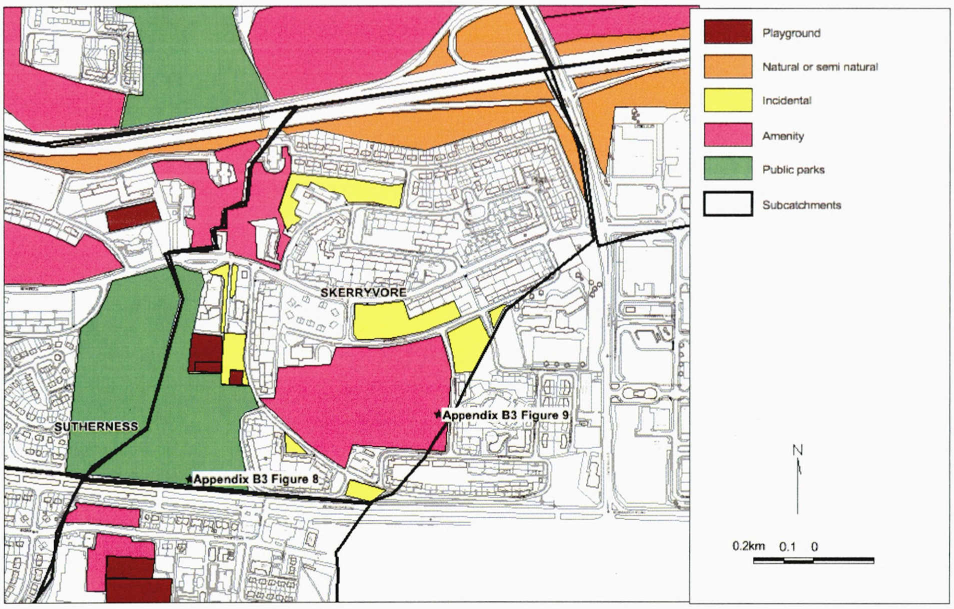
Figures 3 to 5 shows that there are several green spaces in Garthamloch where site control and regional control SUDS could be located.

Skerryvore Place



Appendix B3 Figure 6: Spatial green space planning in Skerryvore

(Map Source: Glasgow City Council)



Appendix B3 Figure 7: Photo locations for Skerryvore (Appendix B3 Figures 6 and 7)

(Map Source: Glasgow City Council)

Appendix B3 Figure 8: Amenity area in Cranhill Park

(Source: Google Street view)

There are potential site for SUDS in Cranhill Park which is low lying and provides ample space. Cranhill Park contains recreational grass areas, children's facilities, mini-golf course, playgrounds, walking and sitting areas.

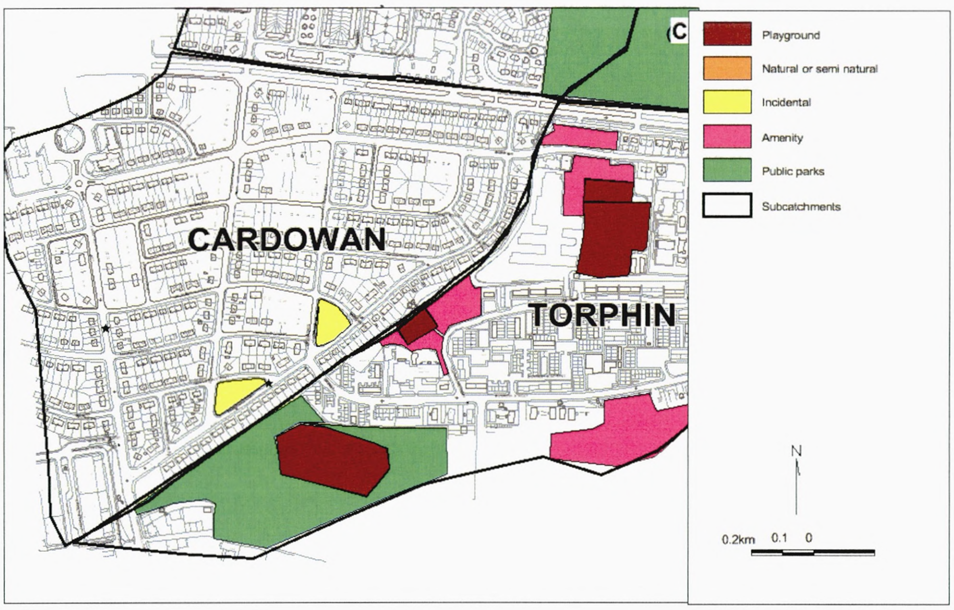
Appendix B3 Figure 9: Recreational area beside a sport club inside Cranhill Park

(Source: Google Street view)

Appendix B3 Figure 10: Green space at Langness Rd lacks good access

(Source: Google Street view)

Potential site for SUDS are shown in Figures 8 and 9. The sites already contain some vegetation which would be further enhanced by adding SUDS such as ponds and detention basins; however the site at Langness Road lacks good access (Figure 10).



Appendix B3 Figure 11: Spatial planning in Cardowan
(Map Source: Glasgow City Council)

The low lying sites have housing but there are no potential SUDS sites in this subcatchment.

APPENDIX B4: INTEGRATED SUDS AND OPEN SPACE PLANNING

Calculations for SUDS in sample subcatchments

The calculations for SUDS in the two sub-catchments have been shown in this section. Regional data for the Glasgow area is presented in Table 1. Input data associated with proportion of land uses are provided in Table 2. Calculations for Greenfield runoff, attenuation volume, treatment volume and sub-catchment storage volumes are shown in Tables 3 to 6. These calculations were carried out assuming each of the sub-catchment completely (100%) contributes to the SUDS. After obtaining attenuation, treatment and long term volumes for the whole sub-catchments, contributing areas were identified from the SUDS plans (section 5.5) and individual SUDS volumes were calculated as a factor of the overall volumes. The calculations for individual SUDS options are shown in Table 7 and Table 8 for Garthamloch and Skerryvore respectively.

Appendix B4 Table 1: Regional input data

	Parameter	Units	Notations	Value
1	Hydrological Region	-	R	2
2	Soil type	-	S	4
3	Annual Rainfall	(mm)	SAAR	1000
4	Soil Runoff Coefficient	-	SPR	0.47
5	Climate Change Factors	-	CC	1.1
6	Attenuation Storage volume per unit area	(m^3/ha)	Uvol1yr	56
7	Atten. Storage volume per unit area	(m^3/ha)	Uvol2yr	70
8	Atten. Storage volume per unit area	(m^3/ha)	Uvol5yr	90
9	Atten. Storage volume per unit area	(m^3/ha)	Uvol10yr	100
10	Atten. Storage volume per unit area	(m^3/ha)	Uvol20yr	125
11	Atten. Storage volume per unit area	(m^3/ha)	Uvol30yr	136
12	Atten. Storage volume per unit area	(m^3/ha)	Uvol100yr	174
13	Atten. Storage volume per unit area	(m^3/ha)	Uvol200yr	197
6	FEH Rainfall factor	-	FF1yr	1.1
7	FEH Rainfall factor	-	FF2yr	1.1
8	FEH Rainfall factor	-	FF5yr	1.1
9	FEH Rainfall factor	-	FF10yr	1.1
10	FEH Rainfall factor	-	FF20yr	1.1
11	FEH Rainfall factor	-	FF30yr	1.1
12	FEH Rainfall factor	-	FF100yr	1.1
13	FEH Rainfall factor	-	FF200yr	1.1
14	Storage Volume Ratio	-	SVR 1yr	1
15	Storage Volume Ratio	-	SVR 2yr	1
16	Storage Volume Ratio	-	SVR 5yr	1
17	Storage Volume Ratio	-	SVR 10yr	1
18	Storage Volume Ratio	-	SVR 20yr	1
19	Storage Volume Ratio	-	SVR 30 yr	1
20	Storage Volume Ratio	-	SVR 100yr	1
21	Storage Volume Ratio	-	SVR 200yr	1
22	Hydrological Region Volume storage ratio	-	HR1yr	1
23	Hydrological Region Vol. storage ratio	-	HR2yr	1
24	Hydrological Region Vol. storage ratio	-	HR5yr	1.03
25	Hydrological Region Vol. storage ratio	-	HR10yr	1.05
26	Hydrological Region Vol. storage ratio	-	HR20yr	1.06
27	Hydrological Region vol. storage ratio	-	HR30yr	1.07
28	Hydrological Region vol. storage ratio	-	HR100yr	1.08
29	Hydrological Region vol. storage ratio	-	HR200yr	1.10
30	Long term Storage Factor	-	LTF	3
31	Rainfall depth	(mm)	RD	55
32	5 year/60 min rainfall depth	(mm)	M560	17

Appendix B4 Table 2: Local input data

Area Name	Notations/Units	Garthamloch	Skerryvore	Cardowan
Area	A (ha)	80	49	49
Public open spaces	(ha)	31	15	1
Developed area	(ha)	48	34	48
Percentage impermeable area	PIMP (%)	1	1	1
Proportion of impervious area requiring impervious storage	ALPHA	1	1	1
Impervious area	AP (ha)	29	29	29

Appendix B4 Table 3: Greenfield runoff calculations

Area Name	Notations/Units	Garthamloch	Skerryvore	Cardowan
Area	A (ha)	48	29	29
Annual Rainfall	SAAR (mm)	1000	1000	1000
Soil Runoff Coefficient	SPR	0.5	0.5	0.5
Catchment annual peak	QBAR (l/s)	353	215	215
Mean annual peak flow per unit area	QBAR/A (l/s/ha)	7	7	7
Peak discharge per unit rate of runoff	Q1yr (l/s)	300	183	183
	Q30yr (l/s)	671	409	409
	Q100yr (l/s)	919	559	560
	Q200yr (l/s)	1060	645	646
1 yr peak discharge per unit rate of runoff	Q1yr/A (l/s)	6	6	6
	Q30yr/A (l/s)	14	14	14
	Q100yr/A (l/s)	19	19	19
	Q200yr/A (l/s)	22	22	22

Appendix B4 Table 4: Attenuation volume results

	Notations	Garthamloch	Skerryvore	Cardowan
Basic storage volumes (m^3)	BSV1yr	2700	1925	2699
	BSV2yr	3375	2407	3373
	BSV5yr	4340	3094	4337
	BSV10yr	4822	3438	4819
	BSV20yr	6028	4298	6024
	BSV30yr	6558	4676	6554
	BSV100yr	8390	5982	8385
	BSV200yr	9499	6773	9493
Adjusted storage volumes (m^3)	ASV1yr	2700	1925	2699
	ASV2yr	3375	2407	3373
	ASV5yr	4340	3094	4337
	ASV10yr	4822	3438	4819
	ASV20yr	6028	4298	6024
	ASV30yr	6558	4676	6554
	ASV100yr	8390	5982	8385
	ASV200yr	9499	6773	9493
Final estimated attenuation storage volumes (m^3)	At.Vol.1yr	2700	1925	2699
	At.Vol.2yr	3375	2407	3373
	At.Vol.5yr	4470	3187	4467
	At.Vol.10yr	5063	3610	5060
	At.Vol.20yr	6389	4555	6385
	At.Vol.30yr	7017	5003	7013
	At.Vol.100yr	9062	6461	9056
	At.Vol.200yr	10449	7450	10443

Appendix B4 Table 5: Treatment volume calculations

Area Name	Notations/ Units	Garthamloch	Skerryvore	Cardowan
Development Area	A (ha)	48	34	48
PIMP	PIMP (%)	1	1	1
Impervious area requiring storage	BETA	1	1	1
Soil runoff coefficient	SPR	0	0	0
5 year/60 min rainfall depth	M560 (mm)	17	17	17
Treatment Vol	TV	5091	3629	5087

Appendix B4 Table 6: Subcatchment storage requirements

Area name		Garthamloch	Skerryvore	Cardowan
Final estimated Attenuation Volume (m^3)	2yr	3375	2407	3373
	5yr	4470	3187	4467
	10 yrs	5063	3610	5060
	30 yrs	7017	5003	7013
Treatment volume, TV (m^3)		5091	3629	5087
Long term volume, LTV(m^3)		4774	4844	4847
Total volume (m^3)		17198	12262	17187

Appendix B4 Table 7: Calculations for individual SUDS options in Garthamloch

Option	1	2	3		4		5	
	Pond	Wet basin	Pond 1	Pond 2	Basin 1	Basin 2	Pond 1	Pond 2
Contributing locations	GCA2+ GCA3	GCA2+ GCA3	GCA2	GCA3	GCA2	GCA3	GCA1	GCA2+ GCA3
Contributing areas (ha)	11	11	7	4	7	4	27	11
Proportion of total areas	0.2	0.2	0.2	0.1	0.2	0.1	0.6	0.2
Attenuation volume (m^3)	1601	1155	1019	582	735	420	3929	1601
Treatment volume (m^3)	1161	1161	739	422	822	422	2850	1161
Basin volume (m^3)		2316			1557	842		
Pond volume (m^3)	3923		2497	1427			9630	3923
Limiting discharge (l/s)	81	81	51	29	51	29	198	81
Overflow discharge (l/s)	0	10	8	3	4	4	48	19
Long term volume (m^3)	0	477	396	143	191	191	2387	955

Appendix B4 Table 8: Proposed proportion of developments contributing to attenuation and long term volumes

	Proportion of developed area contributing to attenuation volume	Proportion of developed area contributing to long term volume
Option 1	0.23	0
Option 2	0.23	0.1
Option 3	0.23	0.11
Option 4	0.23	0.08
Option 5	0.8	0.7

Appendix B4 Table 9: Calculations for individual SUDS options in Skerryvore

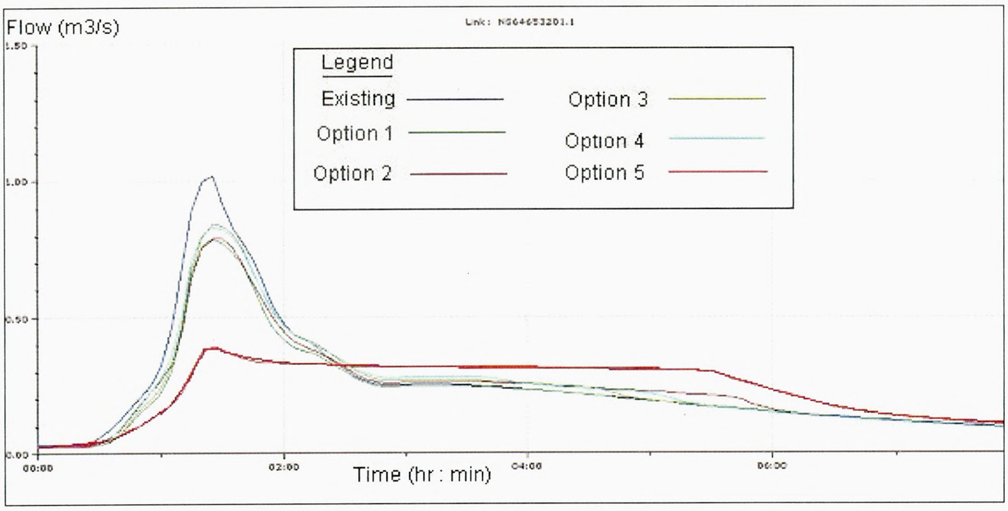
Option	1	2	3	4	5		
	Pond	Wet basin	Dry basin	Wet basin	Wet basin 1	Wet basin 2	Pond
Contributing locations	SCA1+ SCA2	SCA1+ SCA2	SCA1	SCA1	SCA1	SCA2	SCA1+ SCA2
Contributing areas (ha)	34.4	34.4	24.0	24.0	24.0	10.0	34.4
Proportion of total areas	1.0	1.0	0.7	0.7	0.7	0.3	1.0
Attenuation volume (m^3)	5003.0	3609.9	2520.0	2520.0	2520.0	1050.0	
Treatment volume (m^3)	3629.5	3629.5	2533.7	2533.7	2533.7	1055.7	3629.5
Basin volume (m^3)		7239.4	5053.7	5053.7	5053.7	2105.7	
Pond volume (m^3)	12262						8652.1
Limiting discharge (l/s)	252.0	252.0	175.9	175.9	175.9	73.3	252.0
Overflow discharge (l/s)	55.0	27.5	20.6	13.8	6.9	6.9	0.0
Long term volume (m^3)	2692.8	1346.4	1009.8	673.2	0	0	336.6

Appendix B4 Table 10: Proposed proportion of developments contributing to attenuation and long term volumes

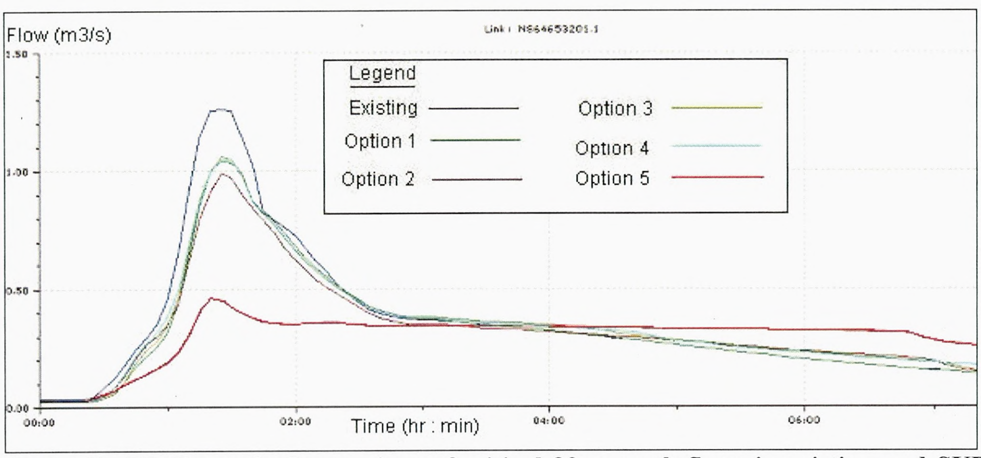
	Proportion of developed area contributing to attenuation volume	Proportion of developed area contributing to long term volume
Option 1	1	0.8
Option 2	1	0.4
Option 3	0.7	0.3
Option 4	0.7	0.2
Option 5	1	0.1

APPENDIX B5: HYDRAULIC EVALUATION OF SUDS OPTIONS

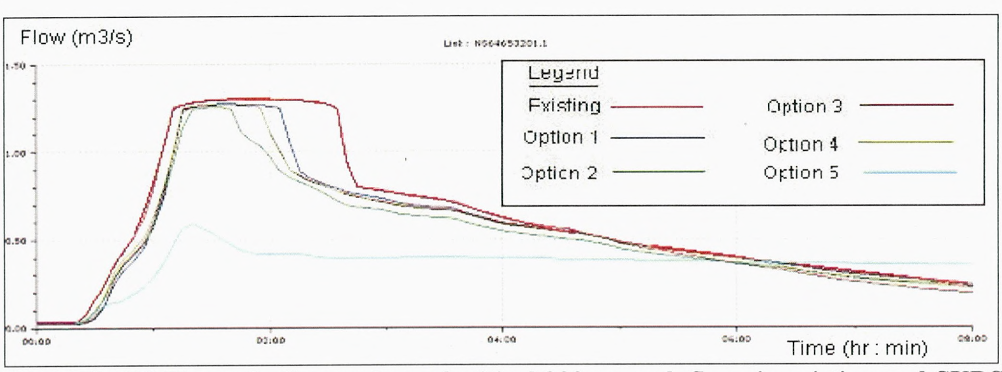
Existing flows are compared with peak flows of various SUDS options. Figures 1 to 3 show the comparison of critical peak flows for 10, 30 and 200 yrs in existing and SUDS scenarios for Garthamloch. Similarly, Figures 4 to 6 show peak flow comparisons for Skerryvore.



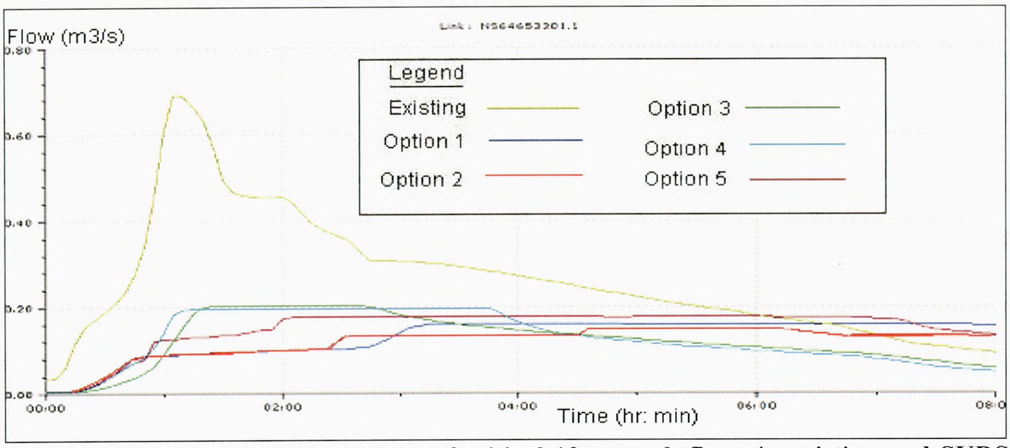
Appendix B5 Figure 1: Comparison of critical 10 yr peak flows in existing and SUDS scenarios for Garthamloch



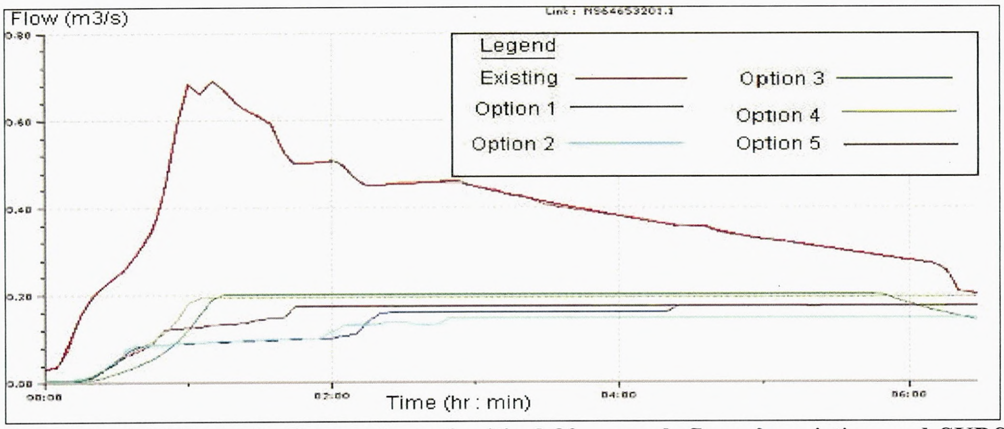
Appendix B5 Figure 2: Comparison of critical 30 yr peak flows in existing and SUDS scenarios for Garthamloch



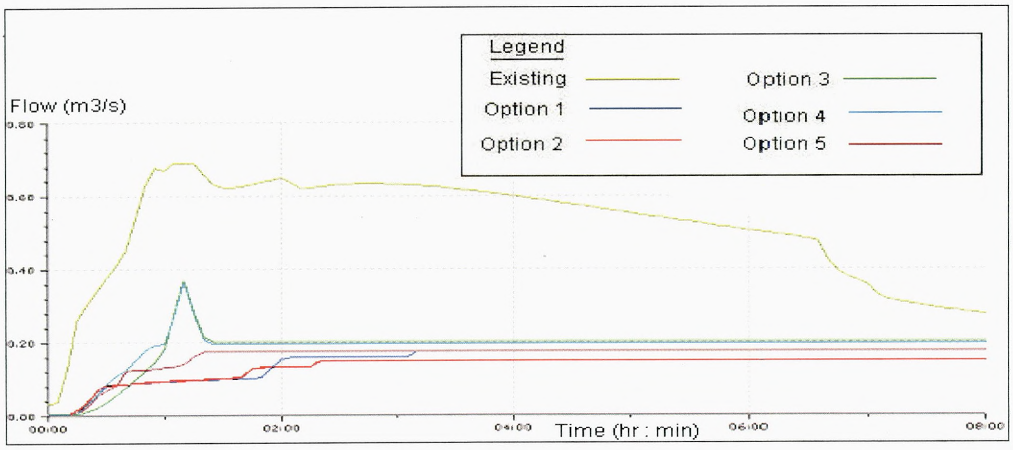
Appendix B5 Figure 3: Comparison of critical 200 yr peak flows in existing and SUDS scenarios for Garthamloch



Appendix B5 Figure 4: Comparison of critical 10 yr peak flows in existing and SUDS scenarios for Skerryvore



Appendix B5 Figure 5: Comparison of critical 30 yr peak flows in existing and SUDS scenarios for Skerryvore



Appendix B5 Figure 6: Comparison of critical 200 yr peak flows in existing and SUDS scenarios for Skerryvore

APPENDIX B6: EVALUATING INTEGRATED SUSTAINABLE DRAINAGE AND OPEN SPACE PLANNING

The process of scoring of SUDS indicators for various options is shown in Appendix B6. Attribute points were provided for each indicator and associated attributes of each option (based on the criteria evolved in Chapter 4) which are shown in Table 1 to Table 5 for Garthamloch and Table 8 to Table 12 for Skerryvore respectively. The normalised weight for each indicator and the summary of attribute points are presented in Table 6 and Table 13 for Garthamloch and Skerryvore respectively. Attribute points are multiplied with normalised weights to obtain indicator scores shown as shown in Table 7 and Table 14 for Garthamloch and Skerryvore respectively.

Calculations and explanations for scoring of Garthamloch options

Appendix B6 Table 1: Attributes and attribute points associated with Option 1 (Pond)

	Indicators	Attribute points	Attributes associated
Option 1	Access	1	Site not connected with footpaths or roads
(One pond)	Water visibility	3	Permanent pool of water in proposed pond
	Aesthetics	3	Diversity of wildlife and vegetation along with the presence of water could give a high aesthetic value.
	passive security	1	Isolated Site
	Multi-purpose	2	Storage and a good recreational potential.
	Safety	1	Proposed pond depth greater than 1m
	Ownership	3	Public
	Flood return period	3	30 yrs return period
	Attenuation volume	1	Less than one third connected to attenuation volume.
	Long term storage	1	Less than one third connected to long term storage

Appendix B6 Table 2: Attributes and attribute points associated with Option 2 (Wet basin)

	Indicators	Attribute points	Attributes associated
Option 2	Access	1	Site not connected with footpaths or roads
	Water visibility	2	Site will have presence of some standing water (between 1Vt and 2Vt)
	Aesthetics	1	A good variety of vegetation as well as presence of some water
	passive security	1	Isolated site
	Multi-purpose	2	Storage and a good recreational potential.
	Safety	2	Depressed ground with standing water of depth less than 1m
	Ownership	3	Public
	Flood return period	2	10 yrs return period
	Attenuation volume	1	Less than one-thirds area connected to attenuation volume
	Long term storage	1	Less than one-thirds area connected to long term storage

Appendix B6 Table 3: Attributes and attribute points associated with Option 3 (Two Ponds)

	Indicators	Attribute points	Attributes associated
Option 3	Access	3	Both footpath and vehicular access available at site
	Water visibility	3	Permanent pool of water in proposed pond
	Aesthetics	3	Diversity of wildlife and vegetation along with the presence of water could give a high aesthetic value.
	passive security	3	Buildings and roads on all sides
	Multi-purpose	2	Storage and a good recreational potential.
	Safety	1	Proposed pond depth greater than 1m
	Ownership	3	Public
	Flood return period	3	30 yrs return period
	Attenuation volume	1	Less than one-thirds area connected to attenuation volume
	Long term storage	1	Less than one-thirds area connected to long term storage

Appendix B6 Table 4: Attributes and attribute points associated with Option 4 (Two dry basins)

	Indicator	Attribute points	Attributes associated
Option 4	Access	3	Accessible by both roads and footpaths
	Water visibility	1	Dry
	Aesthetics	1	Low aesthetic value due to single vegetation of short grasses and no water
	passive security	3	Presence of roads and buildings all around
	Multi-purpose	1	Only storage as its function
	Safety	3	Depressed ground but no standing water
	Ownership	3	Public
	Flood return period	2	10 yrs return period
	Attenuation volume	1	Less than one-thirds area connected to attenuation volume
	Long term storage	1	Less than one-thirds area connected to long term storage

Appendix B6 Table 5: Attributes and attribute points associated with Option 5 (Two Ponds)

	Indicator	Attribute points	Attributes associated
Option 5	Access	1	Site not connected with footpaths or roads
	Water visibility	3	Permanent pool of water in proposed pond
	Aesthetics	3	Diversity of wildlife and vegetation along with the presence of water could give a high aesthetic value.
	passive security	1	Located in isolated area
	Multi-purpose	2	Storage and a good recreational potential.
	Safety	1	Depth greater than 1m
	Ownership	3	Public
	Flood return period	3	30 yrs return period
	Attenuation volume	3	More than two-thirds area connected to attenuation volume
	Long term storage	3	More than two-thirds area connected to long term storage

Appendix B6 Table 6: Normalised weightings and attribute points associated with all options in Garthamloch

Indicators	Normalised weightings	Option 1	Option 2	Option 3	Option 4	Option 5
Access	0.6	1	1	3	3	1
Water visibility	0.7	3	2	3	1	3
Aesthetics	0.7	3	1	3	1	3
passive security	0.6	1	1	3	3	1
Multi-purpose	0.8	2	2	2	1	2
Safety	0.8	1	2	1	3	1
Ownership	0.7	3	3	3	3	3
Flood return period	1.7	3	2	3	2	3
Attenuation volume	1.6	1	1	1	1	3
Long term storage	1.6	1	1	1	1	3

Appendix B6 Table 7: Scores of SUDS options for Garthamloch

Indicators	Option 1	Option 2	Option 3	Option 4	Option 5
Access	0.6	0.6	1.8	1.8	0.6
Water visibility	2.1	1.4	2.1	0.7	2.1
Aesthetics	2.1	0.7	2.1	0.7	2.1
passive security	0.6	0.6	1.8	1.8	0.6
Multi-purpose	1.6	1.6	1.6	0.8	1.6
Safety	0.8	1.6	0.8	2.4	0.8
Ownership	2.1	2.1	2.1	2.1	2.1
Flood return period	5.1	3.4	5.1	3.4	5.1
Attenuation volume	1.6	1.6	1.6	1.6	4.8
Long term storage	1.6	1.6	1.6	1.6	4.8
total score	18.2	15.2	20.6	16.9	24.6

Note:

Normalised scores were obtained by multiplication of individual scores with weights

Calculations and explanations for scoring of Skerryvore options

Appendix B6 Table 8: Attributes and attribute points associated with Option 1 (Pond)

	Indicator	Attribute points	Attributes associated
Option 1	Access	2	Site connected only with footpath, vehicular access for maintenance may need to be developed
	Water visibility	3	Permanent pool of water in proposed pond
	Aesthetics	3	Diversity of wildlife and vegetation along with the presence of water could give a high aesthetic value.
	passive security	2	Presence of roads and buildings on two sides
	Multi-purpose	3	Storage and SUDS recreational potential. Additional recreational potential due to presence of nearby recreational facilities, and park setting.
	Safety	1	Proposed pond depth greater than 1m
	Ownership	3	Public
	Flood return period	3	flood management up to 30 yrs
	Attenuation volume	3	More than two-thirds area connected to attenuation volume
	Long term storage	3	More than two-thirds area connected to long tem storage

Appendix B6 Table 9: Attributes and attribute points associated with Option 2 (Wet basin)

	Indicator	Attribute points	Attributes associated
Option 2	Access	2	Site connected only with footpath, vehicular access for maintenance may need to be developed
	Water visibility	2	Presence of some standing water (between 1Vt and 2Vt)
	Aesthetics	2	A good variety of vegetation as well as presence of some water
	passive security	2	Presence of roads and buildings on two sides
	Multi-purpose	3	Storage and SUDS recreational potential. Additional recreational potential due to presence of nearby recreational facilities, and park setting.
	Safety	2	Depressed ground with some standing water but depth less than 1m
	Ownership	3	Public
	Flood return period	2	flood management up to 10 yrs
	Attenuation volume	3	More than two-thirds area connected to attenuation volume
	Long term storage	2	Between one-third and two-thirds area connected to long term storage

Appendix B6 Table 10: Attributes and attribute points associated with Option 3 (Dry basin)

	Indicator	Attribute points	Attributes associated
Option 3	Access	2	Site connected only with footpath, vehicular access for maintenance may need to be developed
	Water visibility	1	Dry
	Aesthetics	1	Presence of only single vegetation of short grasses is likely have a low perceived aesthetic value
	passive security	2	Presence of roads and buildings on two sides
	Multi-purpose	3	Storage and SUDS recreational potential. Additional recreational potential due to presence of nearby recreational facilities, and park setting.
	Safety	3	Depressed ground but no standing water
	Ownership	3	Public
	Flood return period	2	End of pipe attenuation
	Attenuation volume	3	More than two-thirds area connected to attenuation volume
	Long term storage	1	Less than one-thirds area connected to long term storage volume

Appendix B6 Table 11: Attributes and attribute points associated with Option 4 (Wet basin)

	Indicator	Attribute points	Attributes associated
Option 4	Access	2	Site connected only with footpath, vehicular access for maintenance may need to be developed
	Water visibility	2	Presence of some standing water (between 1Vt and 2Vt)
	Aesthetics	2	A good variety of vegetation as well as presence of some water
	passive security	2	Presence of roads and buildings on two sides
	Multi-purpose	3	Storage and SUDS recreational potential. Additional recreational potential due to presence of nearby recreational facilities, and park setting.
	Safety	2	Depressed ground with some standing water of depth less than 1m
	Ownership	3	Public
	Flood return period	2	Two levels of attenuation
	Attenuation volume	3	More than two-thirds area connected to attenuation volume
	Long term storage	1	Less than one-thirds area connected to long term storage volume

Appendix B6 Table 12: Attributes and attribute points associated with Option 5 (A pond and two wet basins)

	Indicator	Attribute points	Attributes associated
Option 5	Access	2	Site connected only with footpath, vehicular access for maintenance may need to be developed
	Water visibility	3	Permanent pool of water in proposed pond
	Aesthetics	3	Diversity of wildlife and vegetation along with the presence of water could give a high aesthetic value.
	passive security	2	Presence of roads and buildings on two sides
	Multi-purpose	3	Storage and SUDS recreational potential. Additional recreational potential due to presence of nearby recreational facilities, and park setting.
	Safety	1	Proposed pond depth greater than 1m
	Ownership	3	Public
	Flood return period	3	flood management up to 30 yrs
	Attenuation volume	3	More than two-thirds area connected to attenuation volume
	Long term storage	1	Less than one-thirds area connected to long term storage volume

Appendix B6 Table 13: Normalised weightings and attribute points associated with all options in Skerryvore

Indicators	Normalised weightings	Option 1	Option 2	Option 3	Option 4	Option 5
Access	0.6	2	2	2	2	2
Water visibility	0.7	3	2	1	2	3
Aesthetics	0.7	3	2	1	2	3
passive security	0.6	2	2	2	2	2
Multi-purpose	0.8	3	3	3	3	3
Safety	0.8	1	2	3	2	1
Ownership	0.7	3	3	3	3	3
Flood return period	1.7	3	2	2	2	3
Attenuation volume	1.6	3	3	3	3	3
Long term storage	1.6	3	2	1	1	1

Appendix B6 Table 14: Indicator scores of SUDS options for Skerryvore

Indicators	Option 1	Option 2	Option 3	Option 4	Option 5
Access	1.2	1.2	1.2	1.2	1.2
Water visibility	2.1	1.4	0.7	1.4	2.1
Aesthetics	2.1	1.4	0.7	1.4	2.1
passive security	1.2	1.2	1.2	1.2	1.2
Multi-purpose	2.4	2.4	2.4	2.4	2.4
Safety	0.8	1.6	2.4	1.6	0.8
Ownership	2.1	2.1	2.1	2.1	2.1
Flood return period	5.1	3.4	3.4	3.4	5.1
Attenuation volume	4.8	4.8	4.8	4.8	4.8
Long term storage	4.8	3.2	1.6	1.6	1.6
total score	26.6	22.7	20.5	21.1	21.1

Note:

Normalised scores were obtained by multiplication of individual scores with weights

Appendix B6 Table 14: Indicator scores of SUDS options for Skerryvore

Indicators	Option 1	Option 2	Option 3	Option 4	Option 5
Access	1.3	1.3	1.3	1.3	1.3
Water visibility	2.0	1.3	0.7	1.3	2.0
Aesthetics	2.2	1.5	0.7	1.5	2.2
passive security	1.2	1.2	1.2	1.2	1.2
Multi-purpose	2.3	2.3	2.3	2.3	2.3
Safety	0.8	1.6	2.4	1.6	0.8
Ownership	2.0	2.0	2.0	2.0	2.0
Flood return period	5.4	3.6	3.6	3.6	5.4
Attenuation volume	4.5	4.5	4.5	4.5	4.5
Long term storage	4.8	3.2	1.6	1.6	1.6
total score	23.4	19.4	17.2	17.8	20.2

Note:

Normalised scores were obtained by multiplication of individual scores with weights

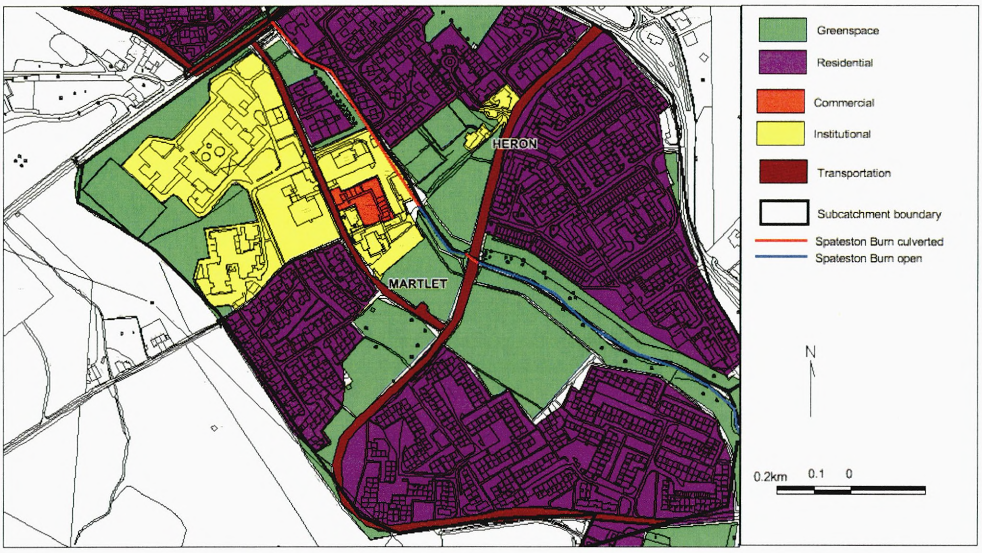
APPENDIX C: DATA AND CALCULATIONS FOR SPATESTON BURN CASE STUDY (CHAPTER 6)

APPENDIX C1: CATCHMENT LAND USE AND DRAINAGE ASSESSMENT

This Appendix shows photos and maps of land use and photos of various sub-catchments in the Spateston catchment. Figures 1 to 6 indicates various aspects indicate land use and drainage of Martlet. Similar aspects for the Heron and Skerryvore sub-catchments are shown in Figures 7 to 12 and Figures 13 to 18 respectively. The photos show the character of the areas discussed in section 5.2, chapter 6. GIS information for land use and drainage layouts of the three sub-catchments are also presented here.

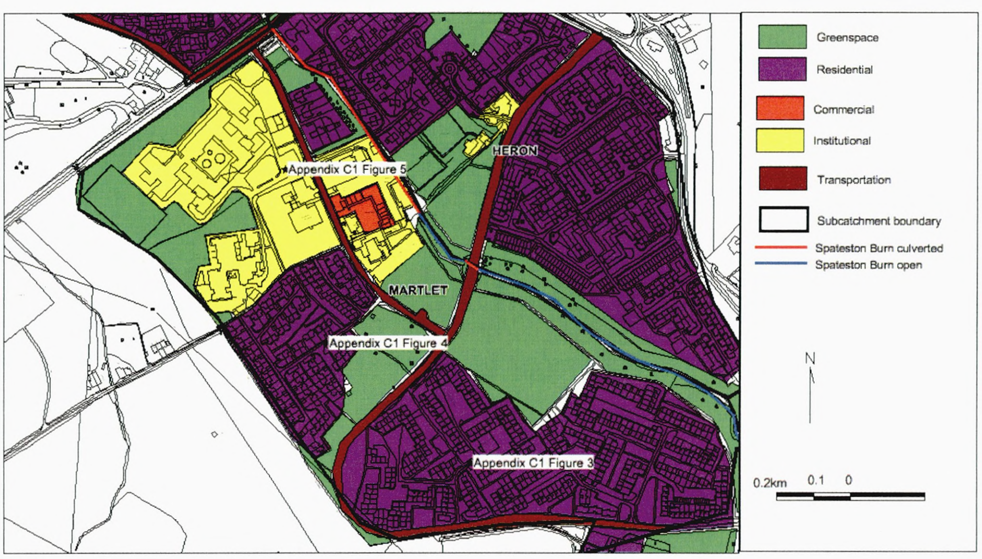
Martlet

Figure 1 shows the spatial planning of Martlet sub-catchment indicating distribution of various land uses. Map of photo locations is presented in Figure 2 while photos of typical housing blocks in Martlet are presented in Figure 3 to Figure 5. The drainage layout of Skerryvore is presented in Figure 6.



Appendix C1 Figure 1: Spatial planning in Martlet

(Map Source: Renfrewshire City Council)



Appendix C1 Figure 2: Photo locations for Martlet (Appendix C1 Figures 3 to 5)

(Map Source: Renfrewshire City Council)

Appendix C1 Figure 3: Nightingale Place in Martlet

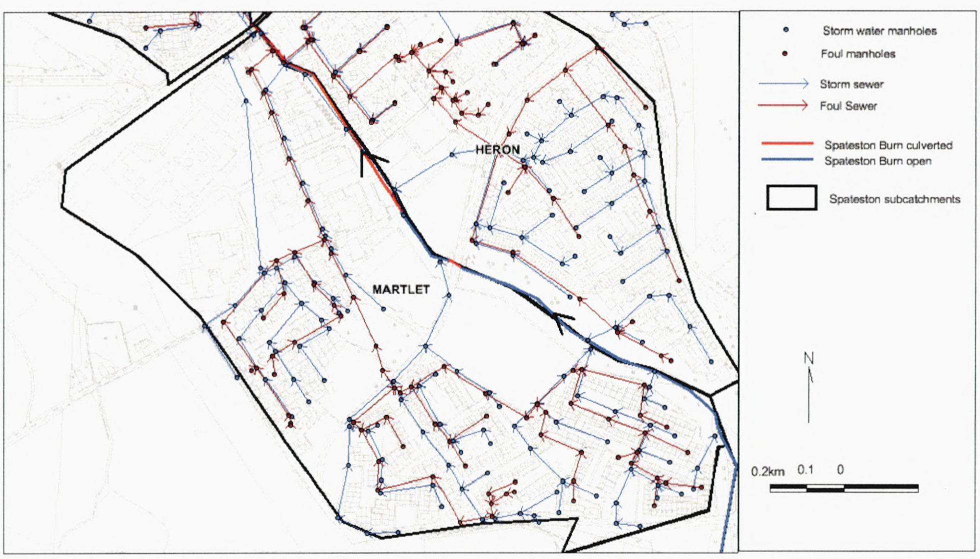
(Source: Google Street view)

Appendix C1 Figure 4: Martlet Drive residential area

(Source: Google Street view)

Appendix C1 Figure 5: Johnstone High School

(Source: Google Street view)

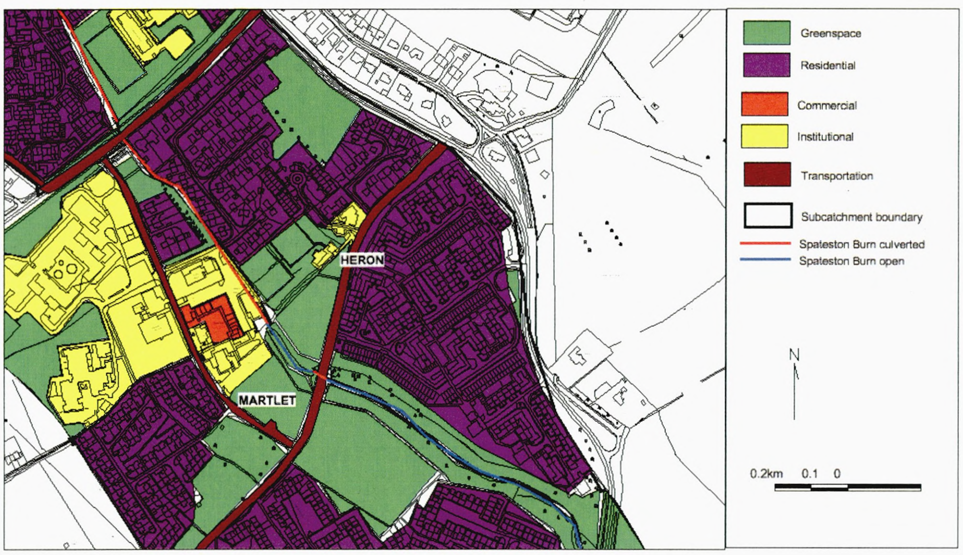


Appendix C1 Figure 6: Drainage layout in Martlet

(Map Source: Renfrewshire Council)

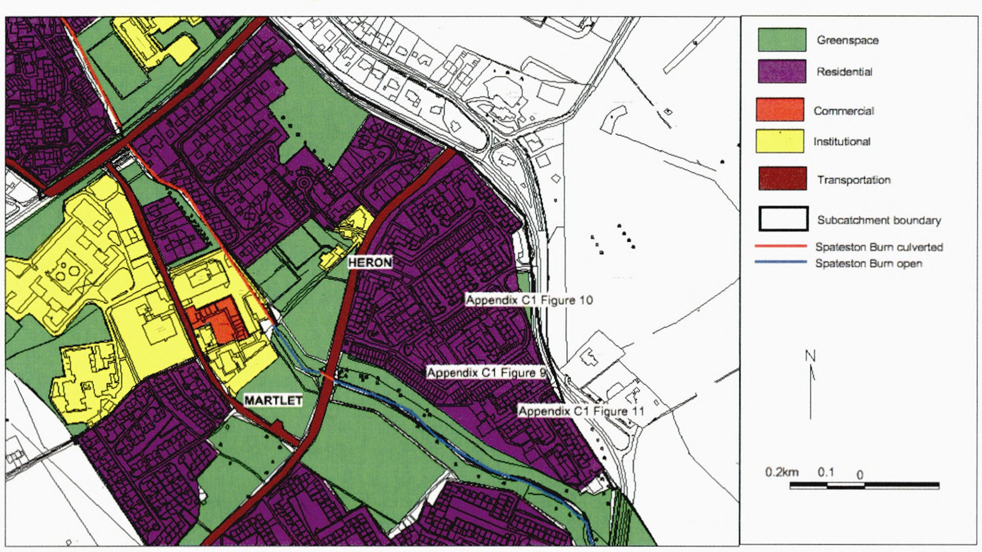
Heron

Figure 7 shows the spatial planning of Heron sub-catchment indicating distribution of various land uses. Map of photo locations is presented in Figure 8 while photos of typical residential blocks in Heron are presented in Figure 9 to Figure 11. The drainage layout in this sub-catchment is presented in Figure 12.



Appendix C1 Figure 7: Spatial Planning in Heron

(Map Source: Renfrewshire Council)



Appendix C1 Figure 8: Photo locations for Heron (Appendix C1 Figures 9 to 11)

(Map Source: Renfrewshire City Council)

Appendix C1 Figure 9: Housing in Falcon Place

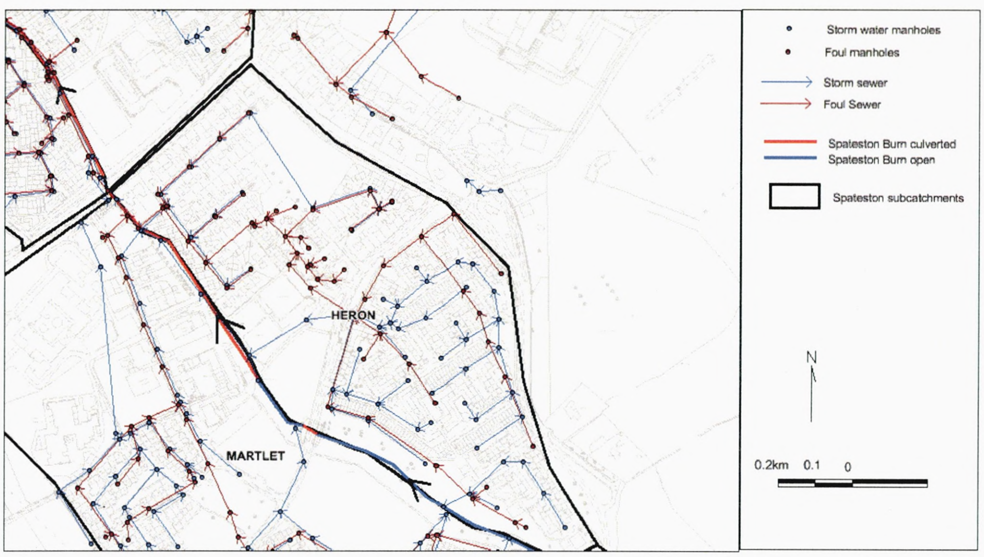
(Source: Google Street view)

Appendix C1 Figure 10: Tenement housing at Heron

(Source: Google Street view)

Appendix C1 Figure 11: Tenement housing at Tern Place

(Source: Google Street view)



Appendix C1 Figure 12: Drainage layout in Heron

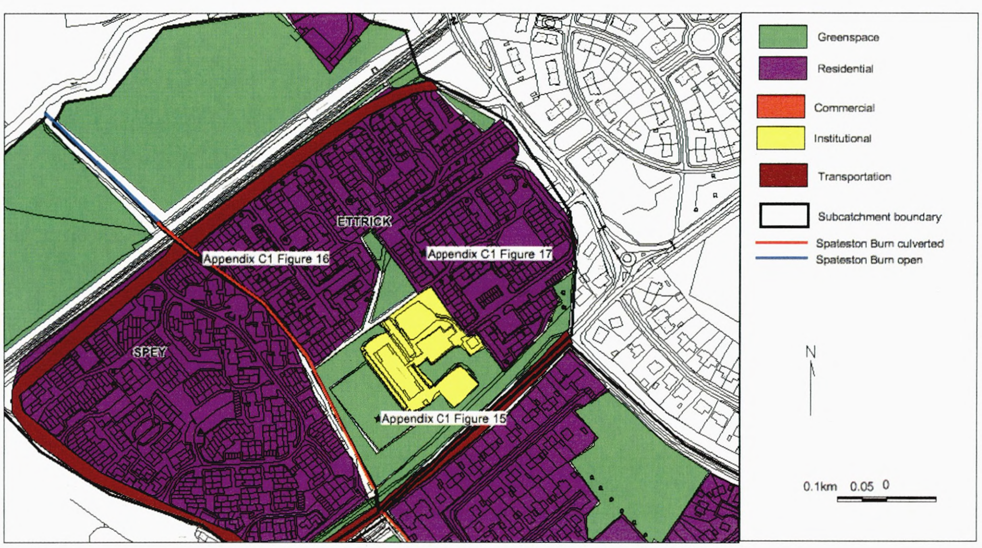
(Map Source: Renfrewshire Council)

Ettrick

Figure 13 shows the spatial planning of Ettrick catchment indicating distribution of various land uses. Map of photo locations is presented in Figure 14 while photos of typical housing areas in Ettrick are presented in Figure 15 to Figure 17. The drainage layout of this sub-catchment is presented in Figure 18.

Appendix C1 Figure 13: Spatial Planning in Ettrick

(Map Source: Renfrewshire Council)



Appendix C1 Figure 14: Photo locations for Ettrick (Appendix C1 Figures 15 to 17)

(Map Source: Renfrewshire Council)

Appendix C1 Figure 15: School in Ettrick

(Source: Google Street view)

Appendix C1 Figure 16: Pedestrian and cycle route in Ettrick

(Source: Google Street view)

Appendix C1 Figure 17: Residential block at Ettrick Terrace

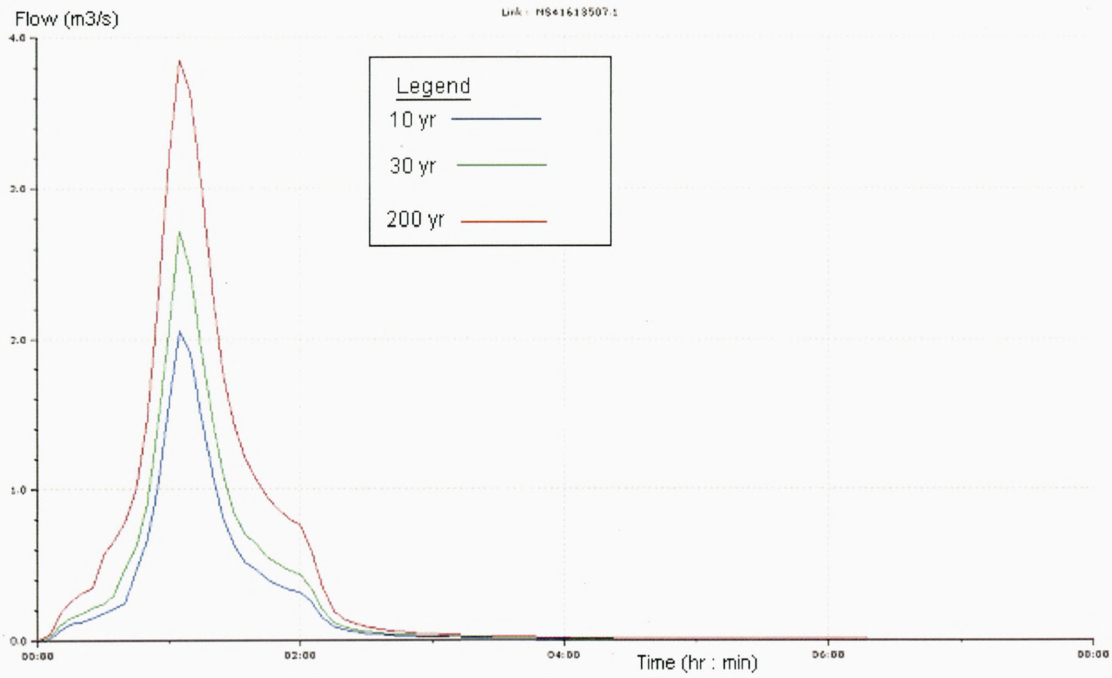
(Source: Google Street view)

Appendix C1 Figure 18: Drainage layout in Ettrick

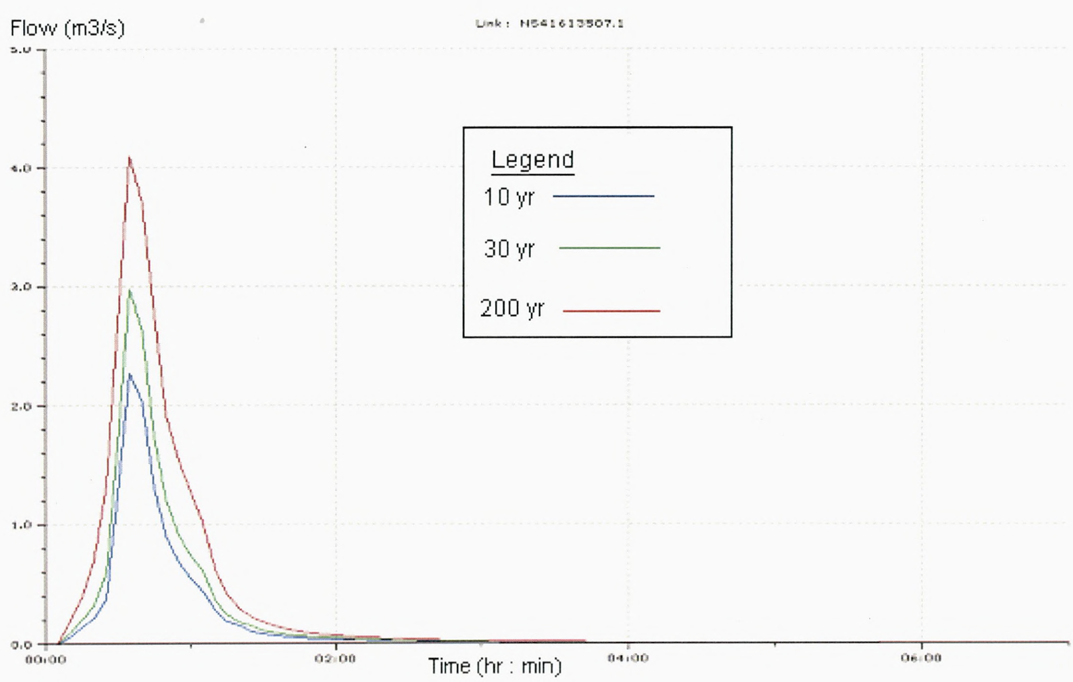
(Source: Renfrewshire Council)

APPENDIX C2: HYDRAULIC ASSESSMENT

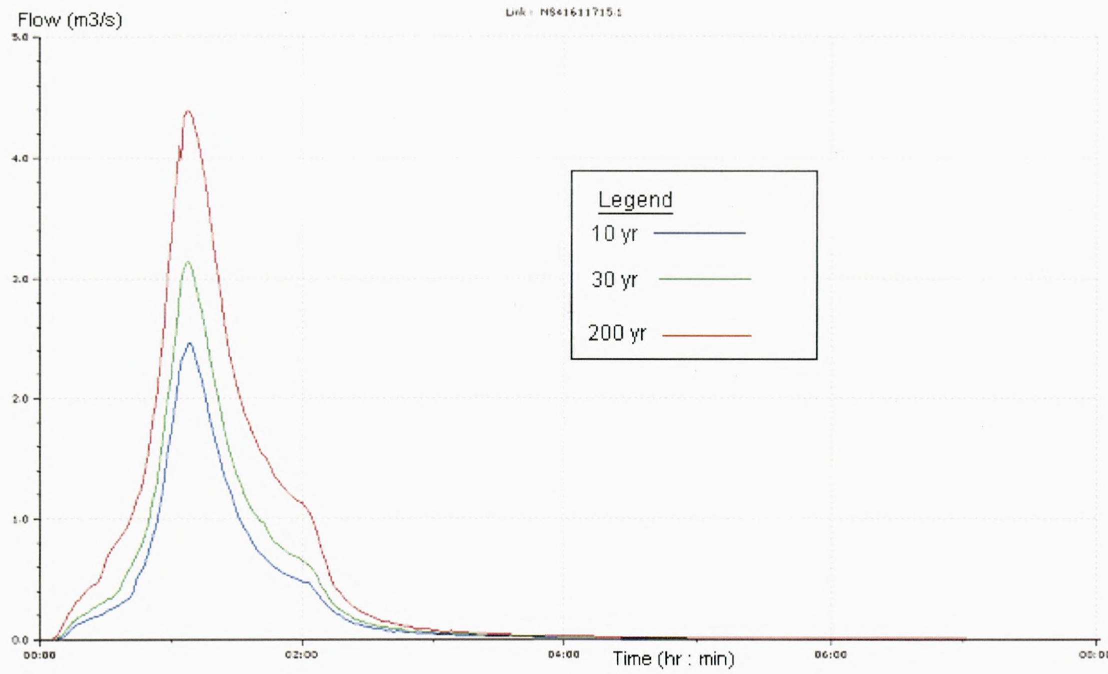
The existing peak flows downstream of selected catchments were determined as discussed in section 6.3 of Chapter 6. The hydrographs at downstream ends for the selected sub-catchments are shown in Figures 1, 2 and 3 while topographical plans with drainage layouts are presented in Figures 4, 5 and 6 respectively.



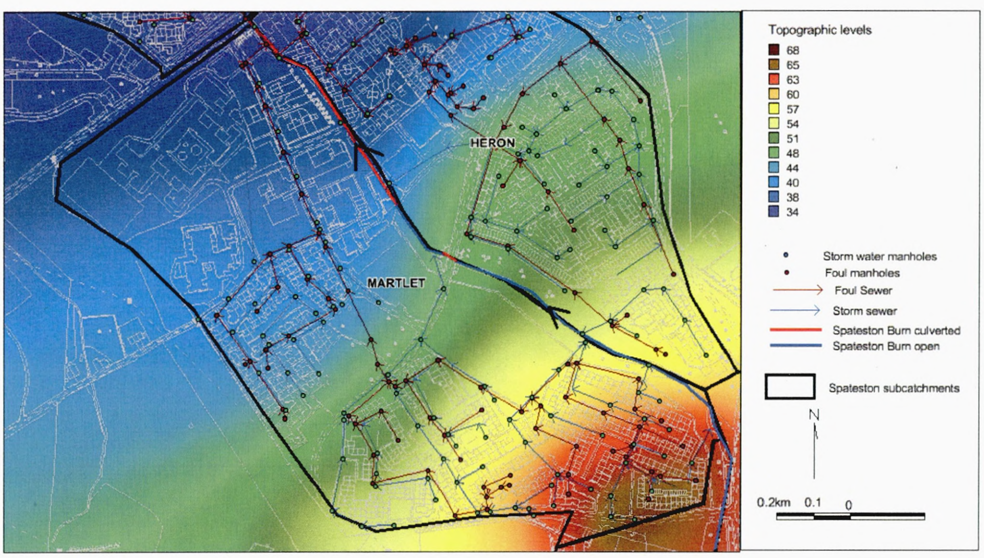
Appendix C2 Figure 1: Peak flows at the outlet of Martlet



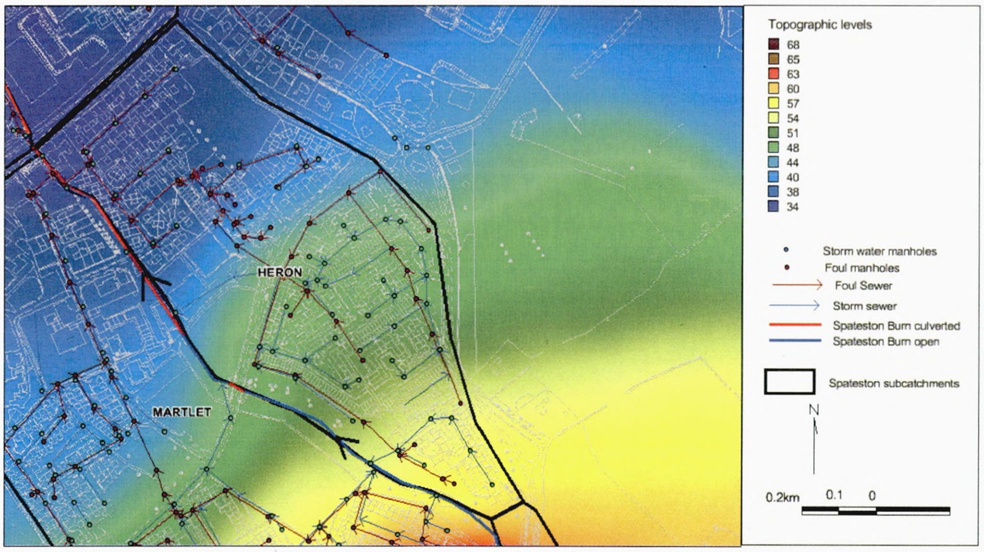
Appendix C2 Figure 2: Peak flows at the outlet of Heron



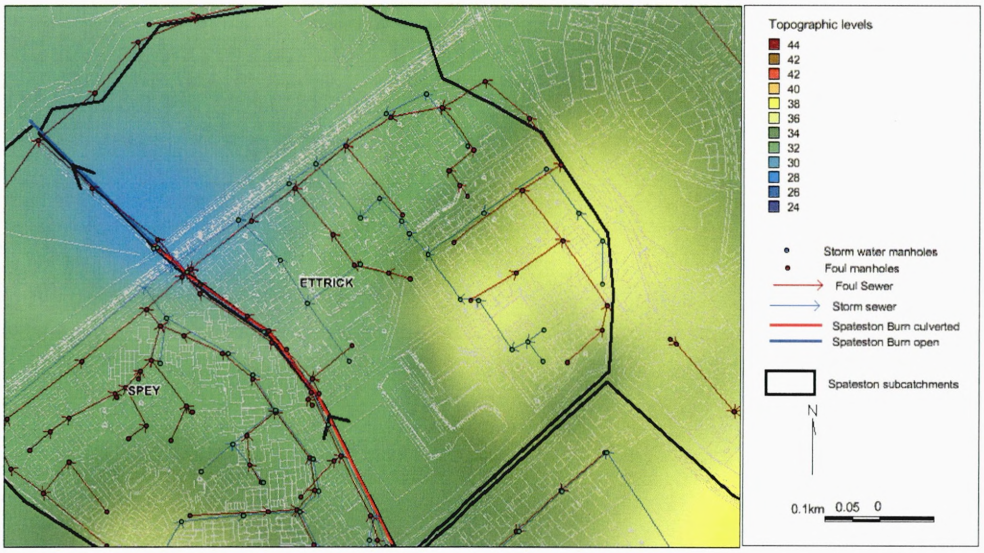
Appendix C2 Figure 3: Peak Flows at the outlet of Ettrick Street



Appendix C2 Figure 4: Topography and drainage in Martlet



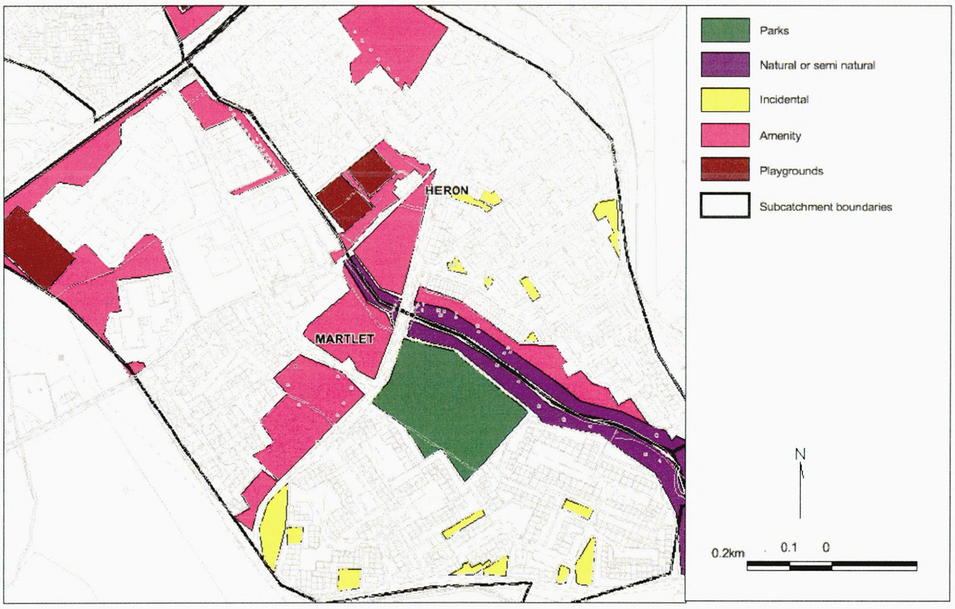
Appendix C2 Figure 5: Topography and drainage in Heron



Appendix C2 Figure 6: Topography and drainage in Ettrick

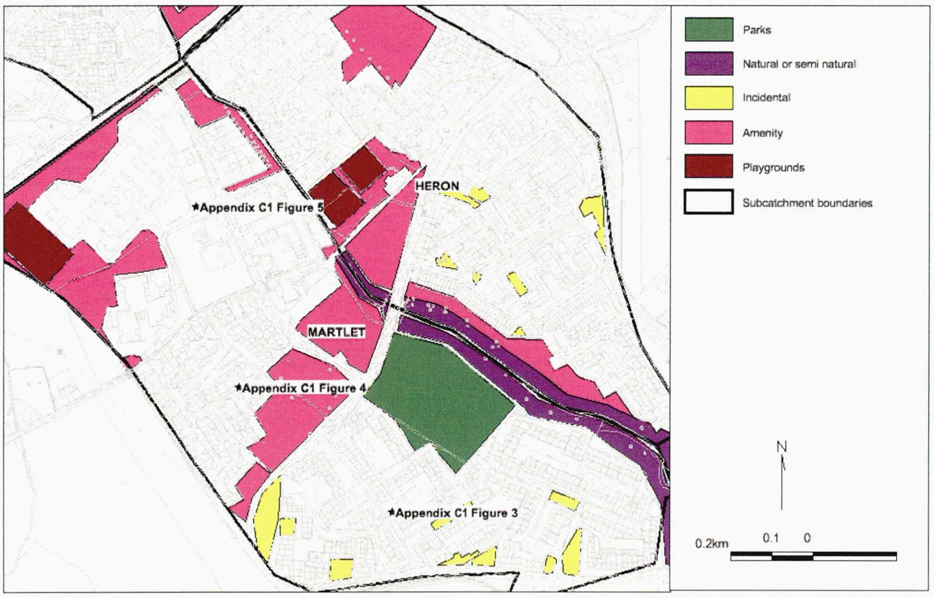
APPENDIX C3: GREEN SPACE ASSESSMENT

Various green space categories and opportunities for SUDS are shown here for the three subcatchments- Martlet, Heron and Ettrick. Figures 1 to 5 show various types of green spaces in Martlet. Green space for Heron and Ettrick are shown in figures 6 to 10 and figures 11 to 14 respectively. As upstream subcatchments were rural, they were not included in assessment.



Appendix C3 Figure 1: Green space distribution in Martlet
(Map source: Renfrewshire Council)

The green spaces beside the Spateston Burn have potential for sustainable drainage (refer to Figure 2).



Appendix C3 Figure 2: Photo locations for Martlet (Appendix C3 Figures 4 to 6)
(Map Source: Renfrewshire City Council)

Appendix C3 Figure 3: Martlet amenity area

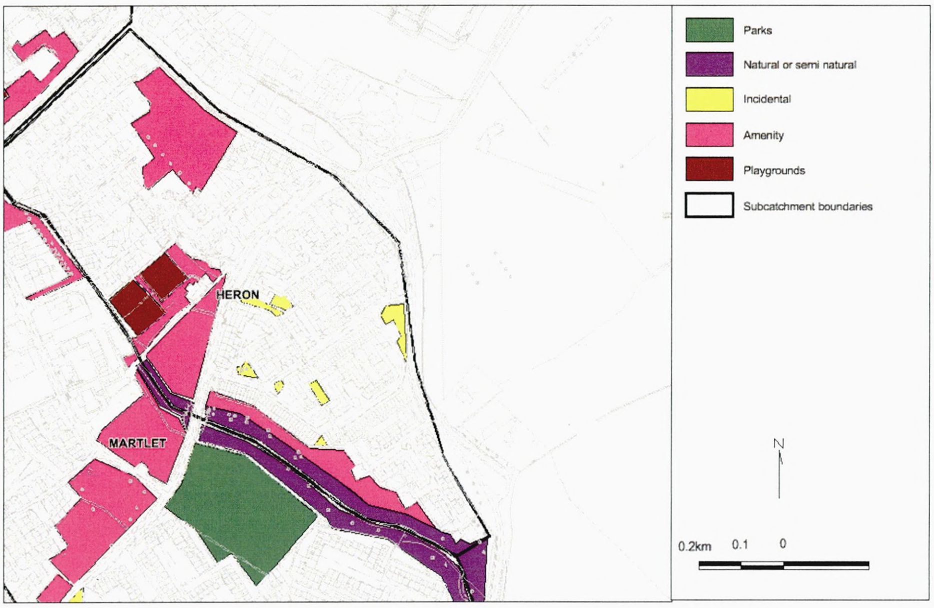
(Source: Google Street view)

Appendix C3 Figure 4: Parkland in Martlet

(Source: Google Street view)

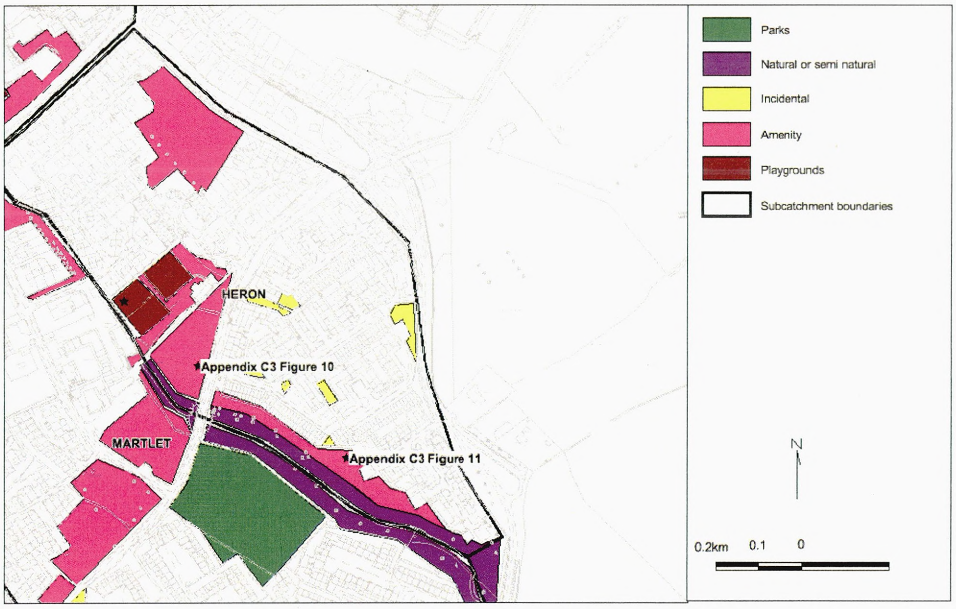
Appendix C3 Figure 5: Amenity green space near Churchill Avenue

(Source: Google Street view)



Appendix C3 Figure 6: Green space distribution in Heron

(Map source: Renfrewshire Council)



Appendix C3 Figure 7: Photo locations for Heron (Appendix C3 Figures 9 to 11)

(Map Source: Renfrewshire City Council)

In figure 7 the site west of Spateston burn can be for SUDS storage.

Appendix C3 Figure 8: Unused sports pitch which could be used as a SUDS site

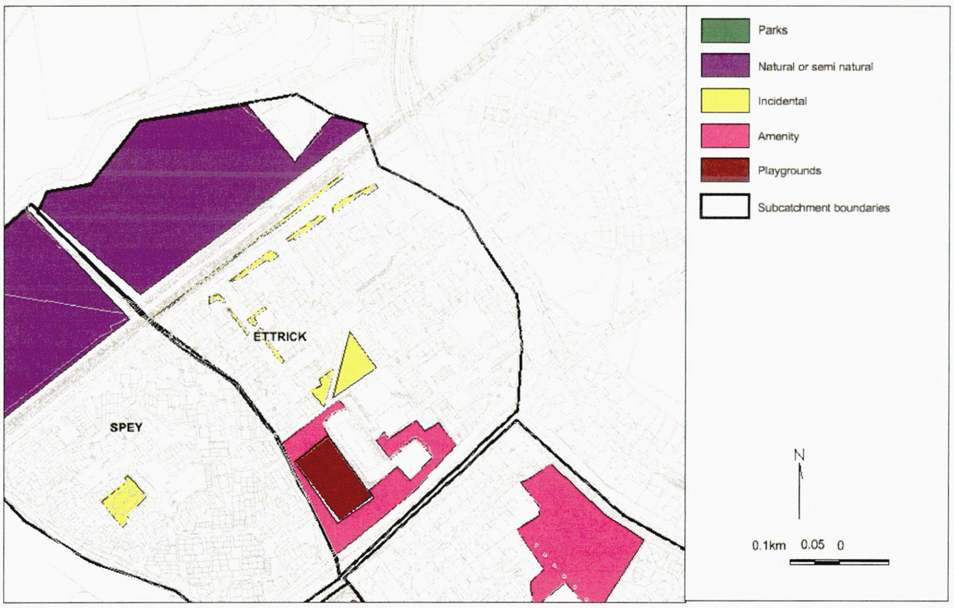
(Source: Google Street view)

Appendix C3 Figure 9: Amenity green space in Heron

(Source: Google Street view)

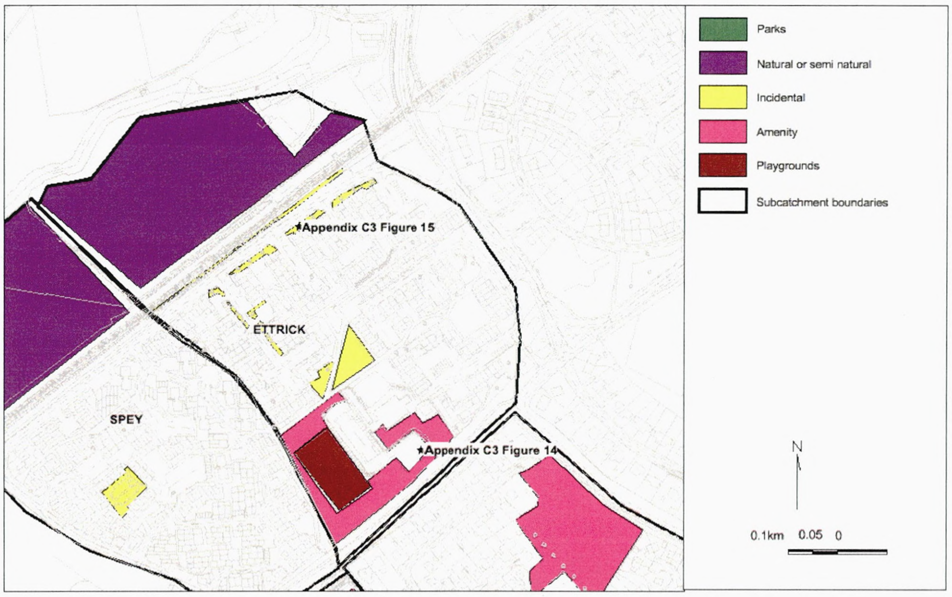
Appendix C3 Figure 10: Amenity green space suitable for SUDS site

(Source: Google Street view)



Appendix C3 Figure 11: Green space distribution in Ettrick
(Map source: Renfrewshire Council)

There is little scope for planning of SUDS in Ettrick. From figures 12 it is evident that the railway line in the south would cause hindrance for potential attenuation near the Black Cart River.



Appendix C3 Figure 12: Photo locations for Ettrick (Appendix C3 Figures 14, 15)
(Map source: Renfrewshire Council)

Appendix C3 Figure 13: Incidental green spaces beside Beith Road

(Source: Google Street view)

Appendix C3 Figure 14: Incidental green spaces beside Coursefield Road

(Source: Google Street view)

APPENDIX C4: INTEGRATED SUDS AND OPEN SPACE PLANNING

Calculations for Spateston SUDS options

Calculations of SUDS for the three sub-catchments are shown in this section. Tables 1 to 5 shows calculations of various SUDS parameters considering 100% of the developed areas are contributing to SUDS. After obtaining attention, treatment and Long term volumes for the whole sub-catchments, contributing areas were identified from the SUDS plans (Appendix C4, Figures 1 to 8) and individual SUDS volumes were calculated as a factor of the overall volumes. Table 6 and Table 7 shows the calculations for various SUDS options in two sub-catchments where SUDS are possible.

Appendix C4 Table 1: Regional input data

	Parameter	Units		Value
1	Hydrological Region	-	R	2
2	Soil type	-	S	4
3	Annual Rainfall	(mm)	SAAR	1000
4	Soil Runoff Coefficient	-	SPR	0.47
5	Climate Change Factors	-	CC	1.1
6	Attenuation Storage volume per unit area	(m^3/ha)	Uvol1yr	56
7	Atten. Storage volume per unit area	(m^3/ha)	Uvol2yr	70
8	Atten. Storage volume per unit area	(m^3/ha)	Uvol5yr	90
9	Atten. Storage volume per unit area	(m^3/ha)	Uvol10yr	100
10	Atten. Storage volume per unit area	(m^3/ha)	Uvol20yr	125
11	Atten. Storage volume per unit area	(m^3/ha)	Uvol30yr	136
12	Atten. Storage volume per unit area	(m^3/ha)	Uvol100yr	174
13	Atten. Storage volume per unit area	(m^3/ha)	Uvol200yr	197
6	FEH Rainfall factor	-	FF1yr	1.1
7	FEH Rainfall factor	-	FF2yr	1.1
8	FEH Rainfall factor	-	FF5yr	1.1
9	FEH Rainfall factor	-	FF10yr	1.1
10	FEH Rainfall factor	-	FF20yr	1.1
11	FEH Rainfall factor	-	FF30yr	1.1
12	FEH Rainfall factor	-	FF100yr	1.1
13	FEH Rainfall factor	-	FF200yr	1.1
14	Storage Volume Ratio	-	SVR 1yr	1
15	Storage Volume Ratio	-	SVR 2yr	1
16	Storage Volume Ratio	-	SVR 5yr	1
17	Storage Volume Ratio	-	SVR 10yr	1
18	Storage Volume Ratio	-	SVR 20yr	1
19	Storage Volume Ratio	-	SVR 30 yr	1
20	Storage Volume Ratio	-	SVR 100yr	1
21	Storage Volume Ratio	-	SVR 200yr	1
22	Hydrological Region Volume storage ratio	-	HR1yr	1
23	Hydrological Region Volume storage ratio	-	HR2yr	1
24	Hydrological Region Volume storage ratio	-	HR5yr	1.03
25	Hydrological Region Volume storage ratio	-	HR10yr	1.05
26	Hydrological Region Volume storage ratio	-	HR20yr	1.06
27	Hydrological Region volume storage ratio	-	HR30yr	1.07
28	Hydrological Region volume storage ratio	-	HR100yr	1.08
29	Hydrological Region volume storage ratio	-	HR200yr	1.10
30	Long term Storage Factor	-	LTF	3
31	Rainfall depth	(mm)	RD	55
32	5 year/60 min rainfall depth	(mm)	M560	17

Appendix C4 Table 2: Local input data

Parameter		Martlet	Ettrick	Heron
Area (ha)	(ha)	25	12.7	15.6
Public Open spaces (ha)	(ha)	10	0	3.9
Developed Area (ha)	(ha)	15	12.7	11.7
PIMP (%)	(%)	0.6	0.6	0.6
ALPHA	-	1	1	1
AP (ha)	(ha)	9	7.6	7

Appendix C4 Table 3: Greenfield runoff

Parameter		Martlet	Ettrick	Heron
Area	A (ha)	15.0	12.7	11.7
Annual rainfall	SAAR (mm)	1000.0	1000.0	1000.0
Soil runoff coefficient	SPR	0.5	0.5	0.5
Catchment annual peak	QBAR (l/s)	110.0	92.8	85.4
Mean annual peak flow per unit area	QBAR/A (l/s/ha)	7.3	7.3	7.3
Peak discharge per unit rate of runoff	Q1yr (l/s)	93.5	78.9	72.6
	Q30yr (l/s)	209.0	176.4	162.3
	Q100yr (l/s)	286.0	241.4	222.2
	Q200yr (l/s)	330.0	278.5	256.3
1 yr peak discharge per unit rate of runoff	Q1yr/A (l/s)	6.2	6.2	6.2
	Q30yr/A (l/s)	13.9	13.9	13.9
	Q100yr/A (l/s)	19.1	19.1	19.1
	Q200yr/A (l/s)	22.0	22.0	22.0

Appendix C4 Table 4: Attenuation volumes

		Martlet	Ettrick	Heron
Basic storage volumes (m^3)	BSV1yr	840.6	709.5	816.2
	BSV2yr	1050.7	886.9	1049.4
	BSV5yr	1350.9	1140.3	1166.0
	BSV10yr	1501.0	1267.0	1457.5
	BSV20yr	1876.3	1583.8	1585.8
	BSV30yr	2041.4	1723.1	2028.8
	BSV100yr	2611.7	2204.6	2297.0
	BSV200yr	2957.0	2496.0	12.8
Adjusted storage volumes (m^3)	ASV1yr	840.6	709.5	816.2
	ASV2yr	1050.7	886.9	1049.4
	ASV5yr	1350.9	1140.3	1166.0
	ASV10yr	1501.0	1267.0	1457.5
	ASV20yr	1876.3	1583.8	1585.8
	ASV30yr	2041.4	1723.1	2028.8
	ASV100yr	2611.7	2204.6	2297.0
	ASV200yr	2957.0	2496.0	12.8
Final estimated attenuation storage volumes (m^3)	At.Vol.1yr	840.6	709.5	816.2
	At.Vol.2yr	1050.7	886.9	1080.9
	At.Vol.5yr	1391.4	1174.5	1224.3
	At.Vol.10yr	1576.1	1330.4	1545.0
	At.Vol.20yr	1988.8	1678.8	1696.8
	At.Vol.30yr	2184.3	1843.7	2191.1
	At.Vol.100yr	2820.7	2380.9	2526.7
	At.Vol.200yr	3252.7	2745.6	38.5

Appendix C4 Table 5: Treatment volumes

Parameter		Martlet	Ettrick	Heron
Development area (ha)	A	15.0	12.7	11.7
PIMP %	PIMP	0.6	0.6	0.6
Proportion of impervious area requiring storage	BETA	0.8	0.8	0.8
Soil runoff coefficient	SPR	0.5	0.5	0.5
5 year/60 min rainfall depth (mm)	M_560	17.0	17.0	17.0
Treatment volume (m^3)	TV	1584.6	1337.6	1230.9

Appendix C4 Table 6: Calculations for individual SUDS options in Martlet

Option No.	1	2	3		4			
	Pond	Basin	Basin1	Basin2	Basin1	Basin2	Pond1	Pond2
Contributing areas (ha)	MC2	MC2	MC2	MC1	MC2	MC1	MC1+ MC2	MC4
Areas (ha)	6	6	6	3	6	3	8	6
Proportion of total areas (ha)	0.37	0.37	0.37	0.2	0.23	0.2	0.53	0.42
Attenuation volume (m^3)	800	578	578	315	578	315	222	923
Treatment volume (m^3)	581	581	581	317	359	486	845	669
Basin volume (m^3)		1158	578	315	357	483		
Attenuation volume (30yr-10yr)							324	
Limiting discharges (l/s)	40.3	40.3	40.3	22	40.3	22	58.6	46.5
Overflow discharge (l/s)	9	4.5	0	0	6	3	0	12
Long term volume (m^3)	446	223	297	149	0	594	446	223

Appendix C4 Table 7: Proposed proportion of developments contributing to attenuation and long term volumes

	Proportion of developed area contributing to attenuation volume	Proportion of developed area contributing to long term volume
Option 1	0.4	0.3
Option 2	0.4	0.15
Option 3	0.57	0
Option 4	0.9	0.7

Appendix C4 Table 8: Calculations for individual SUDS options in Heron

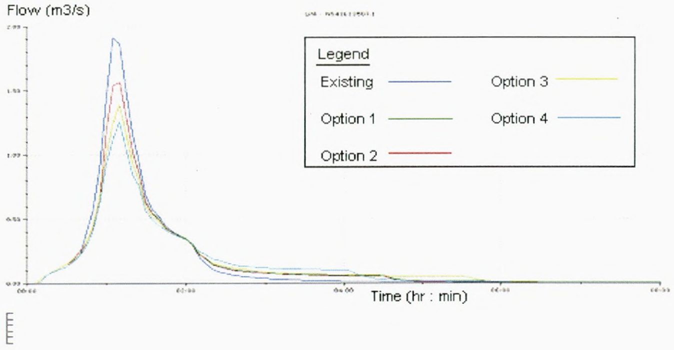
Option	1	2	3		4	
	Pond	basin	basin	pond	Basin1	Basin2
Contributing areas (ha)	HCA2	HCA2	HCA1	HCA2	HCA1	HCA2
Areas (ha)	6	6	1	6	1	6
Proportion of total areas (ha)	0.51	0.51	0.07	0.51	0.07	0.51
Attenuation volume (m^3)	1128	795	114	1128	114	795
Treatment volume (m^3)	633	633	91	633	91	633
Basin volume (m^3)		1428	205		205	1428
Pond volume (m^3)	2395			2394		
Limiting discharges (l/s)	44	44	6.3	44	6.3	44
Overflow discharge (l/s)	4.7	15	0	0	0	9
Long term volume (m^3)	231	577	0	0	0	346

Appendix C4 Table 9: Proposed proportion of developments contributing to attenuation and long term volumes

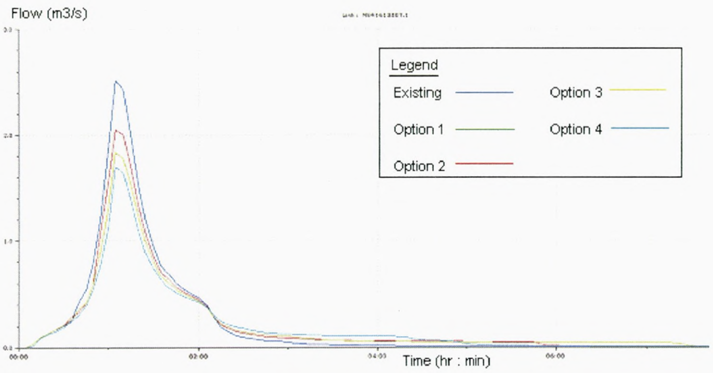
	Proportion of developed area contributing to attenuation volume	Proportion of developed area contributing to long term volume
Option 1	0.5	0.2
Option 2	0.5	0.5
Option 3	0.58	0
Option 4	0.58	0.3

APPENDIX C5: HYDRAULIC EVALUATION OF SUDS OPTIONS

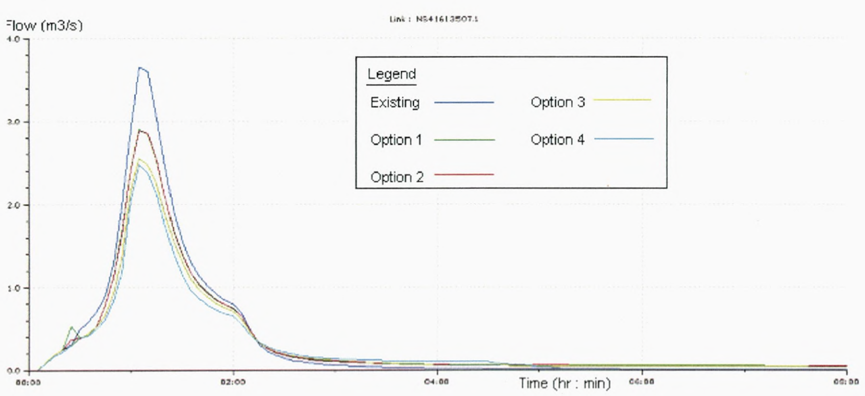
Existing flows are compared with peak flows of various SUDS options. Figures 1 to 3 show the comparison of critical peak flows for 10, 30 and 200 yrs in existing and SUDS scenarios for Martlet. Similarly, Figures 4 to 6 show peak flow comparisons for Heron.



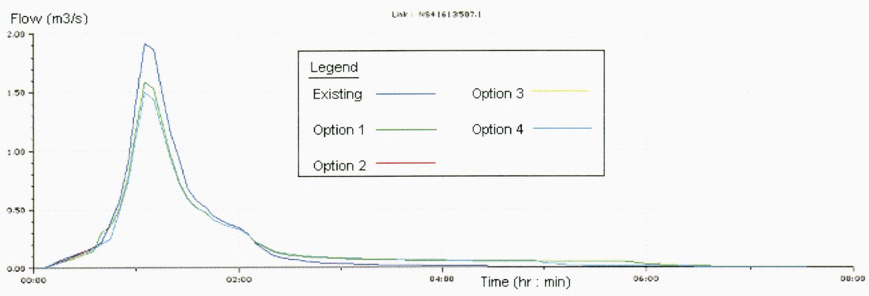
Appendix C5 Figure 1: Comparison of critical 10 yr peak flows in existing and SUDS scenarios for Martlet Drive



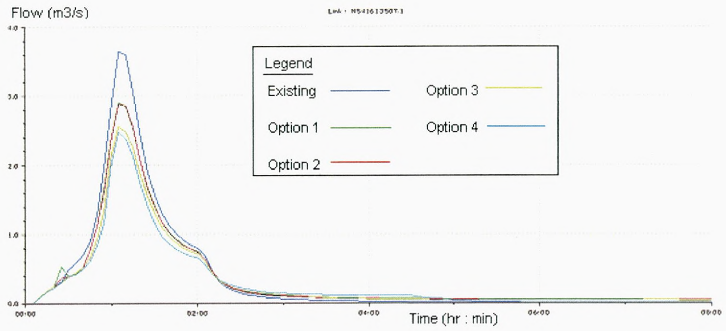
Appendix C5 Figure 2: Comparison of critical 30 yr peak flows in existing and SUDS scenarios for Martlet Drive



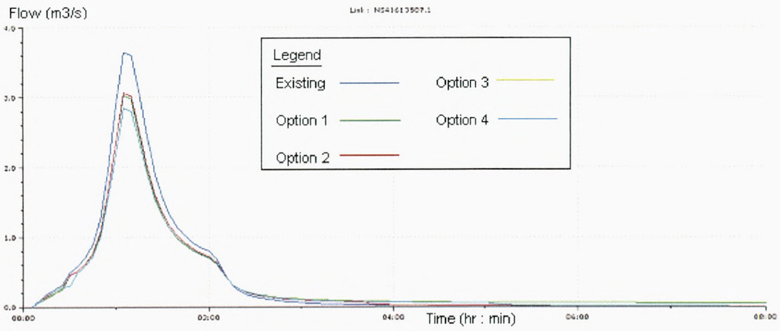
Appendix C5 Figure 3: Comparison of critical 200 yr peak flows in existing and SUDS scenarios for Martlet Drive



Appendix C5 Figure 4: Comparison of critical 10 yr peak flows in existing and SUDS scenarios for Heron Place



Appendix C5 Figure 5: Comparison of critical 30 yr peak flows in existing and SUDS scenarios for Heron Place



Appendix C5 Figure 6: Comparison of critical 200 yr peak flows in existing and SUDS scenarios for Heron Place

APPENDIX C6: EVALUATING INTEGRATED SUSTAINABLE DRAINAGE AND OPEN SPACE PLANNING

The process of scoring of SUDS indicators for various options is shown in Appendix C6. Attribute points were provided for each indicator and its associated attributes of each option (based on the criteria evolved in Chapter 4) which are shown in Table 1 to Table 4 for Martlet and Table 7 to Table 10 for Heron respectively. The normalised weight for each indicator and the summary of attribute points are presented in Table 5 and Table 11 for Martlet and Heron respectively. Attribute points are multiplied with normalised weights to obtain indicator scores shown as shown in Table 6 and Table 12 for Martlet and Heron respectively.

Calculations and explanations for scoring of Martlet SUDS options

Appendix C6 Table 1: Attributes and attribute points associated with Option 1 (Pond)

	Indicators	Attribute points	Attributes associated
Option 1	Access	2	Site is accessible from Spateston road and footpaths
	Water visibility	3	Permanent pool of water in proposed pond
	Aesthetics	3	Diversity of wildlife and vegetation along with the presence of water could give a high aesthetic value.
	passive security	2	Proposed SUDS located beside Spateston Road and visible from nearby housing estates
	Multi-purpose	3	Pond designed for both storage and recreation. Additional presence of recreational facilities, park setting
	Safety	1	Proposed pond depth greater than 1m
	Ownership	3	Located in public open space
	Flood return period	3	flood management up to 30 yrs
	Attenuation volume	2	Between two-thirds and one-thirds are connected to attenuation volume
	Long term storage	1	Less than one-thirds area connected to long term storage

Appendix C6 Table 2: Attributes and attribute points associated with Option 2 (Dry Basin)

	Indicators	Attribute points	Attributes associated
Option 2	Access	2	Site is accessible from Spateston road and footpaths
	Water visibility	1	No permanent pool of water
	Aesthetics	1	Dry basin with only grass vegetation
	passive security	2	Proposed SUDS located beside Spateston Road and visible from nearby housing estates
	Multi-purpose	3	Basin designed as kickabout area and storage. Additional presence of nearby recreational facilities, park setting,
	Safety	3	Depressed ground but no standing water
	Ownership	3	Public
	Flood return period	2	Flood management up to 10 yrs
	Attenuation volume	2	Between two-thirds and one-thirds are connected to attenuation volume
	Long term storage	1	Less than one-thirds area connected to long term storage

Appendix C6 Table 3: Attributes and attribute points associated with Option 3 (2 wet basins)

	Indicators	Attribute points	Attributes associated
Option 3	Access	2	Site is accessible from Spateston road and footpaths
	Water visibility	2	Permanent presence of some water in the form of little puddles
	Aesthetics	2	Diversity of wildlife and vegetation along with the presence of water could give a high aesthetic value.
	passive security	3	Proposed SUDS located beside Spateston Road and visible from nearby housing estates
	Multi-purpose	3	Basin designed for both storage and recreation. Additional presence of nearby recreational facilities, park setting,
	Safety	2	Proposed pond depth greater than 1m
	Ownership	3	Public
	Flood return period	2	Flood management up to 30 yrs
	Attenuation volume	2	Between two-thirds and one-thirds are connected to attenuation volume
	Long term storage	0	No long term storage

Appendix C6 Table 4: Attributes and attribute points associated with Option 4 (Two ponds and two basins)

	Indicators	Attribute points	Attributes associated
Option 4	Access	3	The pond site in Secondary school is highly accessible. Other site is accessible from Spateston road and footpaths
	Water visibility	3	Permanent pool of water in proposed pond
	Aesthetics	3	Diversity of wildlife and vegetation along with the presence of water could give a high aesthetic value.
	passive security	3	Buildings roads all around the site
	Multi-use	3	Pond located inside school could be made multi-functional with sitting and meeting areas
	Safety	1	Proposed pond depth greater than 1m
	Ownership	3	Institutional
	Flood return period	3	Flood management up to 30 yrs
	Attenuation volume	3	More than two-thirds area connected to attenuation volume
	Long term storage	3	More than two-thirds area connected to long term storage volume

Appendix C6 Table 5: Normalised weightings and attribute points associated with all options in Martlet

indicators	Normalised Weightings	Option 1	Option 2	Option 3	Option 4
Access	0.6	2	2	2	3
Water visibility	0.7	3	1	2	3
Aesthetics	0.7	3	1	2	3
passive security	0.6	2	2	3	3
Multi-purpose	0.8	3	3	3	3
Safety	0.8	1	3	2	1
Ownership	0.7	3	3	3	3
Flood return period	1.7	3	2	2	3
Attenuation volume	1.6	2	2	2	3
Long term storage	1.6	1	1	0	3

Appendix C6 Table 6: Scores of SUDS options for Martlet

	Option 1	Option 2	Option 3	Option 4
Access	1.2	1.2	1.2	1.8
Water visibility	2.1	0.7	1.4	2.1
Aesthetics	2.1	0.7	1.4	2.1
passive security	1.2	1.2	1.8	1.8
Multi-purpose	2.4	2.4	2.4	2.4
Safety	0.8	2.4	1.6	0.8
Ownership	2.1	2.1	2.1	2.1
Flood return period	5.1	3.4	3.4	5.1
Attenuation volume	3.2	3.2	3.2	4.8
Long term storage	1.6	1.6	0	4.8
total score	21.8	18.9	18.5	27.8

Note:

Normalised scores were obtained by multiplication of individual scores with weightings

Calculations and explanations for scoring of Heron SUDS options

Appendix C6 Table 7: Attributes and attribute points associated with Option 1 (Pond)

	Indicators	Attribute points	Attributes associated
Option 1	Access	3	Site is accessible by footpath and a road Churchill Avenue
	Water visibility	3	Permanent pool of water in proposed pond
	Aesthetics	3	Diversity of wildlife and vegetation along with the presence of water could give a high aesthetic value.
	passive security	3	Buildings roads all around the site
	Multi-purpose	2	Designed for storage and recreation
	Safety	1	Proposed pond depth greater than 1m
	Ownership	3	Public
	Flood return period	3	flood management up to 30 yrs
	Attenuation volume	2	Between two-thirds and one-thirds are connected to attenuation volume
	Long term storage	1	Less than one-thirds area connected to long term storage

Appendix C6 Table 8: Attributes and attribute points associated with Option 2 (Dry basin)

	Indicators	Attribute points	Attributes associated
Option 2	Access	3	Site is accessible by footpath and a road Churchill Avenue
	Water visibility	1	No permanent pool of water
	Aesthetics	1	Dry basin with only grass vegetation
	passive security	3	Buildings roads all around the site
	Multi-purpose	1	Designed for storage only.
	Safety	3	Depressed ground but no standing water
	Ownership	3	Public
	Flood return period	2	flood management up to 10 yrs
	Attenuation volume	2	Between two-thirds and one-thirds are connected to attenuation volume
	Long term storage	2	Between two-thirds and one-thirds are connected to long term storage

Appendix C6 Table 9: Attributes and attribute points associated with Option 3 (A Pond and a wet basin)

	Indicators	Attribute points	Attributes associated
Option 3	Access	3	Site is accessible by footpath and a road Churchill Avenue
	Water visibility	3	Permanent pool of water in proposed pond
	Aesthetics	3	Diversity of wildlife and vegetation along with the presence of water could give a high aesthetic value.
	passive security	3	Buildings roads all around the site
	Multi-purpose	2	Storage and recreation will be provided by the pond
	Safety	1	Proposed pond depth greater than 1m
	Ownership	3	Public
	Flood return period	3	flood management up to 30 yrs
	Attenuation volume	2	Between two-thirds and one-thirds are connected to attenuation volume
	Long term storage	0	No long term storage

Appendix C6 Table 10: Attributes and attribute points associated with Option 4 (Two wet basins)

	Indicators	Attribute points	Attributes associated
Option 4	Access	3	Site is accessible by footpath and a road Churchill Avenue
	Water visibility	2	Permanent presence of some water in the form of little puddles
	Aesthetics	2	Basin has a variety of vegetation such as native grass, shrubs and trees
	passive security	3	Buildings roads all around the site
	Multi-purpose	2	Designed for dual purpose (storage and recreation)
	Safety	1	Depressed ground with some standing water but depth less 1m
	Ownership	3	Public
	Flood return period	2	flood management up to 10 yrs
	Attenuation volume	2	Between two-thirds and one-thirds are connected to attenuation volume
	Long term storage	1	Less than one-thirds area connected to long term storage

Appendix C6 Table 11 Normalised weightings and attribute points associated with all options in Heron

Indicators	Normalised Weightings	Option 1	Option 2	Option 3	Option 4
Access	0.6	3	3	3	3
Water visibility	0.7	3	1	3	2
Aesthetics	0.7	3	1	3	2
passive security	0.6	3	3	3	3
Multi-purpose	0.8	2	1	2	2
Safety	0.8	1	3	1	2
Ownership	0.7	3	3	3	3
Flood return period	1.7	3	2	3	2
Attenuation volume	1.6	2	2	2	2
Long term storage	1.6	1	2	0	1

Appendix C6 Table 12: Scores of SUDS options for Heron

Indicators	Option 1	Option 2	Option 3	Option 4
Access	1.8	1.8	1.8	1.8
Water visibility	2.1	0.7	2.1	1.4
Aesthetics	2.1	0.7	2.1	1.4
passive security	1.8	1.8	1.8	1.8
Multi-purpose	1.6	0.8	1.6	1.6
Safety	0.8	2.4	0.8	1.6
Ownership	2.1	2.1	2.1	2.1
Flood return period	5.1	3.4	5.1	3.4
Attenuation volume	3.2	3.2	3.2	3.2
Long term storage	1.6	3.2	0	1.6
total score	26.6	22.7	20.5	21.1

Note: Normalised scores were obtained by multiplication of individual scores with weightings